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DEFENCE R&D DÉFENSE

# Synopsis of Survey Data collected during Q-260 MAPLE 2001 sea-trials with CFAV and NRV Alliance

*Mark Trevorrow, Anna Crawford, John Fawcett, Ron Kessell, Terry Miller, Vincent Myers and Mark Rowsome*

**Defence R&D Canada**

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# Synopsis of Survey Data collected during Q-260 MAPLE 2001 sea-trials with CFAV Quest and NRV Alliance

Mark Trevorrow, Anna Crawford, John Fawcett, Ron Kessel, Terry Miller, Vincent Myers, and Mark Rowsome

**Defence Research Establishment Atlantic**

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## Abstract

This memorandum summarizes experimental survey results acquired by the DREA mine counter-measures group during a joint sea-trial with the SACLANT Undersea Research Center, La Spezia, Italy. DREA utilized its ship *CFAV Quest* while the *NRV Alliance* supported the SACLANTCEN effort. The trials were conducted July 1 – 20, 2001 at four sites near Halifax, Nova Scotia. Each of the sites was approximately 1 by 2 km in area, with water depths of 30 to 50 m, overtop of mixed muddy, sandy, or rocky seabeds. At each site, high-resolution sidescan sonar surveys from the *Quest* were combined with multi-beam swath bathymetric sonar surveys from the *Alliance*. The *Quest* successfully deployed a variety of inert mine shapes at two sites, and then collected high-resolution sidescan sonar imagery of these mines at a variety of ranges and incidence angles. This data will be used for developing and testing computer-aided detection and classification algorithms. At the same time *Alliance* focused its efforts on high-frequency seabed backscatter measurements, seabed stereo photography, and core samples. Both vessels collected echo-sounder and sub-bottom profiler data useful for evaluating seabed sediment classification schemes. Multiple deployments of new and existing free-falling sediment penetrometers were conducted.



## Résumé

Le présent document résume les résultats de levés expérimentaux obtenus par le Groupe de lutte contre les mines (MCM) du CRDA dans le cadre d'essais en mer effectués conjointement avec le Centre de recherches du SACLANT, basé à La Spezia (Italie). Le CRDA a utilisé son *navire auxiliaire des Forces canadiennes Quest*, alors que le *navire de recherche de l'OTAN Alliance* appuyait l'effort du SACLANTCEN. Les essais ont été menés du 1er au 20 juillet 2001 à quatre emplacements situés à proximité d'Halifax (Nouvelle-Écosse). Chacun des emplacements avait une étendue d'environ 1 km par 2 km, avec des profondeurs d'eau de 30 à 50 m, recouvrant des fonds marins boueux, sableux ou rocheux mixtes. À chacun des emplacements, on a combiné des levés de sonar à balayage latéral haute résolution effectués à partir du navire *Quest* et des levés de sonar bathymétrique à secteur multifaisceau effectués à partir du navire *Alliance*. Le *Quest* a mis en place avec succès des mines inertes de diverses formes à deux emplacements, puis il en a recueilli des images par sonar à balayage latéral haute résolution à diverses distances et divers angles d'incidence. Les données ainsi recueillies seront utilisées pour élaborer et mettre à l'essai des algorithmes de détection et de classification assistées par ordinateur. En même temps, le navire *Alliance* concentrait ses efforts sur les mesures haute fréquence de rétrodiffusion sur le fond marin, sur la photographie stéréoscopique du fond marin et sur le prélèvement d'échantillons carottés. Les deux navires ont recueilli des données d'échosondeur et du profil sous-marin qui sont utiles pour évaluer les systèmes de classification des sédiments du fond marin. Plusieurs opérations de mise en place de modèles connus et de modèles nouveaux de pénétromètres de sédiments à chute libre ont été effectuées.

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# Executive summary

**Introduction**
During the period 28 June – 20 July 2001 the *NRV Alliance* and scientists from the SACLANT Undersea Research Center, La Spezia, Italy visited Halifax and participated with DREA in high-frequency acoustic mine counter-measure (MCM) studies. This joint scientific effort was known as MAPLE (Measuring the Acoustic Properties of the Littoral Environment) 2001. The DREA MCM group based its operations onboard the *CFAV Quest*. The primary thrust of MAPLE 2001 was to increase understanding of high-frequency sidescan sonar performance in shallow water environments, with specific emphasis on detection of seabed mines. This technical memorandum summarizes the data collected by DREA MCM.

**Principal Results**
High-resolution sidescan sonar surveys from the *Quest* were combined with multi-beam swath bathymetric sonar surveys from the *Alliance* to cover four sites: near Herring Cove, in St. Margaret's Bay, near Rose Bay, and near New Harbour Pt. (all near Halifax, NS). Each of the sites was approximately 1 by 2 km in area, with water depths of 30 to 50 m overtop of mixed muddy, sandy, or rocky seabeds. The *Quest* successfully deployed a variety of inert mine shapes (cylinders, mantas, moored spheres) at both the Herring Cove and St. Margaret's Bay sites, and then collected many hours of high-resolution sidescan sonar imagery of these mines at a variety of ranges and incidence angles. At the same time *Alliance* focused its efforts on high-frequency seabed backscatter measurements, seabed stereo photography, and core samples. Both vessels collected echo-sounder and sub-bottom profiler data useful for evaluating seabed sediment classification schemes. Multiple deployments of new and existing free-falling sediment penetrometers were conducted for evaluation purposes.

**Significance of the Results**
MAPLE 2001 combined DREA and SACLANTCEN capabilities to address research issues on seabed mine detectability and acoustic sediment classification. The bathymetric and sidescan sonar survey areas in St. Margaret's Bay, Rose Bay, and New Harbour Pt. were selected to cover potential exercise areas requested by MARLANT N32.

**Future Plans**
The data collected during these joint sea-trials will fuel ongoing scientific collaboration between DREA and SACLANTCEN. Specific applications include: a) the development and testing of computer-aided detection and classification algorithms for seabed mines, b) evaluation of echo-sounder and sidescan sonar based sediment classification tools, and c) development of improved seabed sediment probes for rapid environmental assessment.

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# Sommaire

**Introduction**
Pendant la période s'étendant du 28 juin au 20 juillet 2001, le *navire de recherche de l'OTAN Alliance* et des scientifiques du Centre de recherches du SACLANT, basé à La Spezia (Italie), ont visité Halifax et ont participé avec le CRDA à des études acoustiques haute fréquence de lutte contre les mines (MCM). Ce projet scientifique conjoint avait pour nom MAPLE 2001 (mesure des propriétés acoustiques du milieu littoral en 2001). Le Groupe de lutte contre les mines (MCM) du CRDA a basé ses opérations à bord du *navire auxiliaire des Forces canadiennes Quest*. MAPLE 2001 visait en premier lieu à permettre une meilleure compréhension des performances du sonar à balayage latéral haute fréquence en eaux peu profondes, et il accordait une importance particulière à la détection des mines du fond marin. Le présent document technique résume les données recueillies par le Groupe de lutte contre les mines (MCM) du CRDA.

**Principaux résultats**
On a combiné les levés de sonar à balayage latéral haute résolution effectués à partir du navire *Quest* et les levés de sonar bathymétrique à secteur multifaisceau effectués à partir du navire *Alliance* de façon à couvrir quatre emplacements : un à proximité de Herring Cove, un dans la baie St. Margaret, un à proximité de Rose Bay et un à proximité de New Harbour Pt. (tous situés près d'Halifax, en N.-É.). Chacun des emplacements avait une étendue d'environ 1 km par 2 km, avec des profondeurs d'eau de 30 à 50 m, recouvrant des fonds marins boueux, sableux ou rocheux mixtes. Aux emplacements de Herring Cove et de la baie St. Margaret, le *Quest* a mis en place avec succès des mines inertes de diverses formes (cylindres, « mantas », sphères amarrées), puis il en a recueilli pendant de nombreuses heures des images par sonar à balayage latéral haute résolution, à diverses distances et divers angles d'incidence. En même temps, le navire *Alliance* concentrait ses efforts sur les mesures haute fréquence de rétrodiffusion sur le fond marin, sur la photographie stéréoscopique du fond marin et sur le prélèvement d'échantillons carottes. Les deux navires ont recueilli des données d'échosondeur et de du profil sous-marin qui sont utiles pour évaluer les systèmes de classification des sédiments du fond marin. Plusieurs opérations de mise en place de modèles connus et de modèles nouveaux de pénétromètres de sédiments à chute libre ont été effectuées à des fins d'évaluation.

**Importance des résultats**
MAPLE 2001 combinait les capacités du CRDA et du SACLANTCEN pour s'attaquer aux sujets de recherche ayant trait à la détectabilité des mines du fond marin et à la classification acoustique des sédiments. Les zones de levé par sonar bathymétrique et par sonar à balayage latéral de la baie St. Margaret, de Rose Bay et de New Harbour

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**Plans pour l'avenir**

Les données recueillies dans ces essais conjoints en mer contribueront à stimuler la collaboration scientifique en cours entre le CRDA et le SACLANTCEN. Les applications particulières comprennent : a) l'élaboration et la mise à l'essai d'algorithmes de détection et de classification des mines du fond marin assistées par ordinateur, b) l'évaluation des outils de classification des sédiments basés sur l'échosondeur et sur le sonar à balayage latéral, c) le développement de sondes améliorées pour les sédiments du fond marin permettant l'évaluation rapide du milieu.

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## Acknowledgments

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# 1. Introduction and Motivation

During the period 28 June – 20 July 2001 the NATO *RV Alliance* from the SACLANT Undersea Research Center, La Spezia, Italy visited Halifax and participated with DREA in high-frequency mine counter-measure (MCM) studies. The DREA MCM group, in collaboration with staff from Trinity/Route Survey Office and scientists from Dalhousie University, based its operations onboard the *CFAV Quest*. These joint sea-trials and ongoing scientific effort are collectively known as MAPLE (Measuring the Acoustic Properties of the Littoral Environment) 2001. This report summarizes the data collected by DREA MCM on the *Quest*.

The overall objective of MAPLE 2001 was to increase understanding of high-frequency sidescan sonar performance in shallow water environments, with emphasis on detection of seabed mines. This is motivated by the fact that in typical mine hunting applications, sonar performance is strongly limited by backscattered reverberation from the seabed (clutter). This is especially true in coastal areas near Halifax which have rough sandy, gravelly, or rocky seabeds. Thus, to understand mine detectability it is necessary both to understand acoustic back-scattering from the seabed at high-frequencies (>100 kHz), and to develop tools to measure sediment properties and oceanographic influences. The MAPLE 2001 sea-trials combined DREA and SACLANTCEN capabilities to make a comprehensive suite of measurements that address these seabed acoustic scattering issues. This is directly relevant to DREA MCM research thrusts, and also relevant to other environmental acoustic activities at DREA. The specific trial objectives were (lead institution in brackets):

1. (DREA) to measure mine signatures as a function of range from the sonar, acoustic frequency, and aspect angle for a variety of realistic mine shapes. Both DREA and SACLANTCEN provided dummy mines, including cylinders, Manta, MP-80, and buoyant bottom-tethered types. These measurements were conducted over two different seabed regions. Overall, this should contribute to the understanding of current sidescan sonar technology for mine detection and aid in the development of computer-assisted detection and classification algorithms.
2. (SACLANTCEN) to measure calibrated acoustic backscatter strength and other seabed scattering statistics as a function of grazing angle and acoustic frequency. Direct comparisons with in situ sediment measurements such as grab samples and stereo photographs will be made. This addresses long-standing deficiencies in quantitative measurement and model validation for seabed backscatter at frequencies above 100 kHz.
3. (SACLANTCEN) to evaluate several new echo-sounder- and sidescan-based seabed classification methods through comparisons with *in situ* seabed sediment property measurements. Several scientific and commercial analysis packages are currently being developed and evaluated for rapid environmental assessment and route-survey purposes.
4. (SACLANTCEN) to evaluate bathymetric multi-beam echo-sounders when used in conjunction with sidescan sonars for rapid environmental assessment, re-alignment of sidescan mosaics, and bottom slope corrections. This data will be useful for testing multi-sensor data fusion concepts.
5. (DREA) to investigate water-borne fluctuations (e.g. currents, boundary layers, internal waves, and turbulence) and their effects on sidescan sonar performance. Specifically,

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these environmental perturbations are thought to increase seabed backscatter variance through acoustic scintillation, and create other distortions through refraction processes. This was assessed through simultaneous collection of acoustic scattering data along with oceanographic measurements such as water temperature-salinity profiles and time-series, current profiles and time-series, turbulent microstructure, and surface weather.

6. (DREA) to test and evaluate prototype free-falling sediment penetrometers. These new devices are intended to give quantitative geo-technical information about the seabed sediments, addressing the need for rapid sediment measurements during sidescan or multi-beam sonar surveys.
7. (DREA) to assist MARLANT N32 with sidescan sonar and multi-beam bathymetric surveys of three specific sites in and between St. Margaret's Bay and Lunenburg Bay.

To contribute towards the above objectives, DREA utilized a variety of ship-board and towed sonars on the *Quest*, including the towed Klein 5500 sidescan sonar, an EdgeTech sub-bottom profiler, a three-frequency Simrad echo-sounder, a RDI 600 kHz ADCP, and the Phantom ROV. The *Alliance* brought a similar suite of echo-sounders and oceanographic systems, including a Simrad EM3000 multi-beam swath bathymetric sonar, a towed steerable narrow-beam sonar, a seabed stereo camera system, and a sediment core-sampler. The two ships worked closely together throughout MAPLE 2001 (see Figure 1), with full exchange of data between the groups and ongoing scientific collaboration in the data analysis.

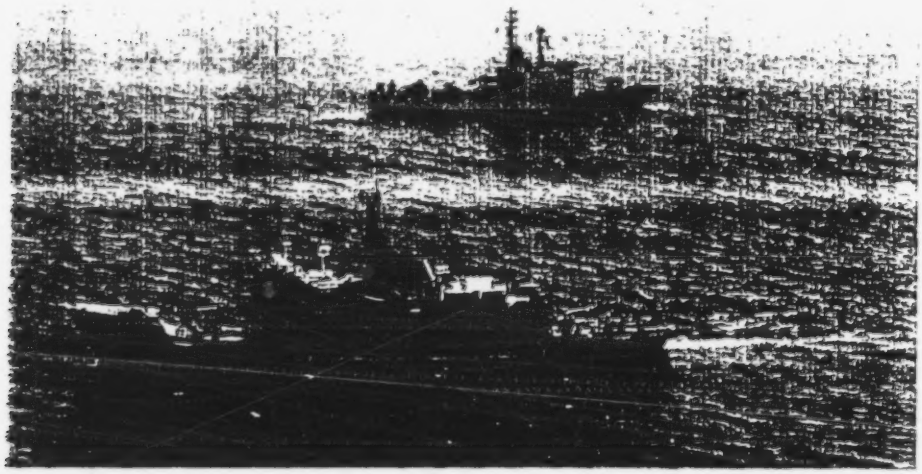

**Figure 1** Aerial photograph of *CFAV Quest* (foreground) and *NRV Alliance* in St. Margaret's Bay, July 13th, 2001

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# 2. Overview of the Survey Areas and Operations

The *Quest* and *Alliance* worked closely during MAPLE 2001 within three main operating areas: SSE of Herring Cove, North-Central St. Margaret's Bay, and outer Rose Bay. Table 2.1 gives dates and site descriptions, with charts of the survey areas shown in Figures 2 - 4. Additionally, on July 19th the *Quest* performed a 4-hour sidescan sonar survey in the vicinity of New Harbour Point. In addition to the main survey areas, short equipment deployment tests were undertaken by the *Quest* in Bedford Basin on July 3rd. A summary of the daily activities on the *Quest* is given in Appendix 1. Unless otherwise noted, henceforth all times are local (Atlantic Daylight Time = UTC-3).

**Table 2.1**: Summary of MAPLE 2001 survey areas

| |
|---|
| **SSE of Herring Cove** |
| *Quest* 0800h July 04 until 1200h July 07; *Alliance* 0800h July 01 until 1800h July 04 |
| SSE of Herring Cove in outer Halifax Harbour, between Lichfield Shoal and Sheehan Cove (CHS Chart 4203), lying within MARLANT Operating Area 'A'. Area bounded approximately by the following coordinates: |
| NW Corner: 44° 34.0′ N, 63° 33.2′ W NE Corner: 44° 34.0′ N, 63° 32.5′ W<br>SW Corner: 44° 32.5′ N, 63° 32.5′ W SE Corner: 44° 32.5′ N, 63° 31.8′ W |
| **North-Central St. Margaret's Bay** |
| *Quest* 0800h July 08 until 1200h July 19; *Alliance* 0800h July 05 until 1200h July 17 |
| Midway between Fox Pt. and Wedge Is., approx. 1.5 nm SSE of Queensland Beach (CHS Chart 4386), lying within MARLANT Operating Area 'B'. Area bounded approximately by the following coordinates: |
| NW Corner: 44° 37.0′ N, 64° 02.0′ W NE Corner: 44° 37.0′ N, 63° 59.0′ W<br>SW Corner: 44° 36.0′ N, 64° 02.0′ W SE Corner: 44° 36.0′ N, 63° 59.0′ W |
| **Outer Rose Bay** |
| *Quest* 1400h July 14 until 2000h July 14, *Alliance* 1200h July 17 until 1400h July 18 |
| Outer Rose Bay, south of Ovens Pt. (CHS Chart 4384), lying within MARLANT Operating Area 'C1'. Area bounded approximately by the following coordinates: |
| NW Corner: 44° 18.5′ N, 64° 14.6′ W NE Corner: 44° 18.9′ N, 64° 13.4′ W<br>SW Corner: 44° 18.2′ N, 64° 14.3′ W SE Corner: 44° 18.6′ N, 64° 13.1′ W |
| **New Harbour Point** |
| *CFAV Quest* 1400h to 1800h July 19; |
| Rocky shoal south of New Harbour Pt. and north of East Ironbound Is. (CHS Chart 4386), lying within MARLANT Operating Area 'C1'. Area bounded by the following coordinates: |
| NW Corner: 44° 27.7′ N, 64° 05.1′ W NE Corner: 44° 27.4′ N, 64° 04.5′ W<br>SW Corner: 44° 27.4′ N, 64° 05.3′ W SE Corner: 44° 27.1′ N, 64° 04.7′ W |

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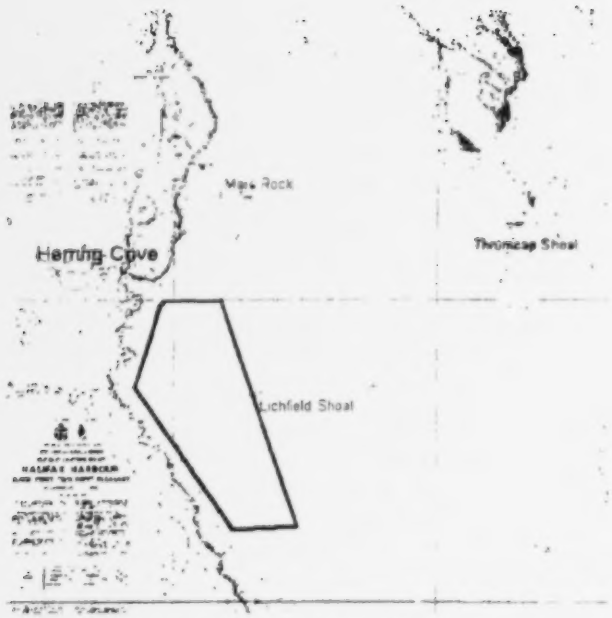


**Figure 2** Portion of Chart 4203 showing survey area SSE of Herring Cove, in outer Halifax Harbour. Light blue areas are <10 m depth.

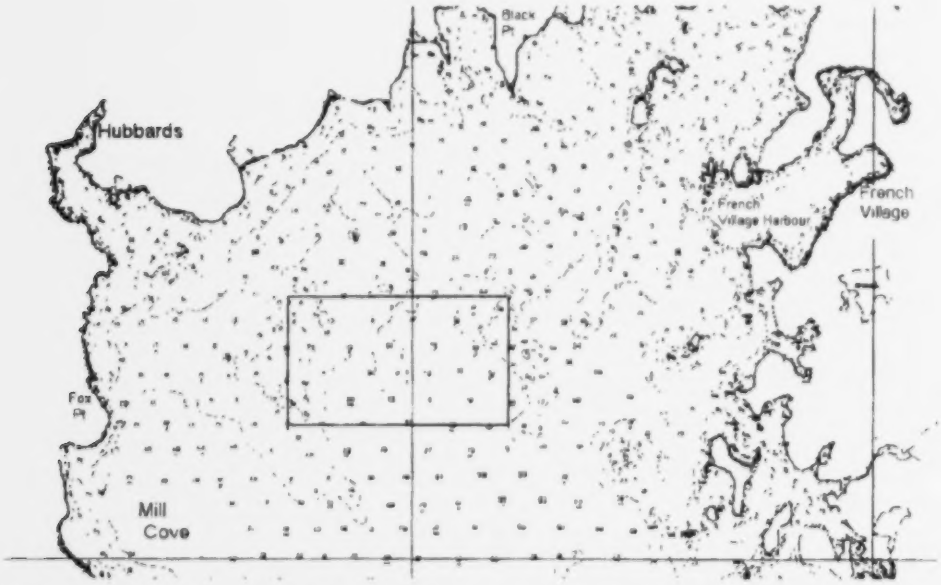


**Figure 3** Portion of Chart 4386 showing survey area in north-central St. Margaret's Bay. Light blue areas are < 5 fathoms.

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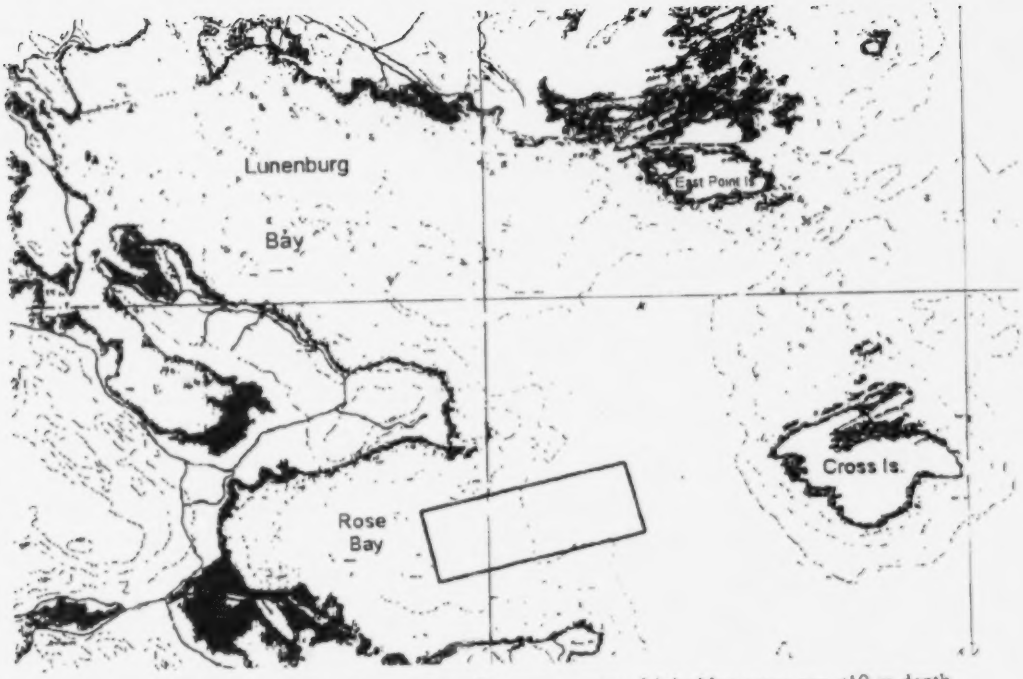


**Figure 4** Portion CHS chart 4384 showing Rose Bay survey area. Light blue areas are <10 m depth.

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# 3. Sidescan Sonar Mosaics and Mine Detection

A key element of these sea-trials was the use of sidescan sonars, both for mapping of the seabed within the operating areas and for detectability trials on inert mine-like objects. On the *Quest*, the towed Klein 5500 was used for both applications. The Klein 5500 sidescan sonar measures high-resolution acoustic back-scatter from the seabed at ranges up 150 m to port and starboard of the ship track-line. The sonar transmits a narrow-band pulse at 455 kHz, utilizing 5 dynamically focused receiver beams per side yielding (in highest resolution mode) a spatial resolution near 10 cm along-track and 3 cm across-track at slant ranges up to 75 m. A low-resolution mode with 20 cm along-track resolution can reach up to 150 m slant range. The sonar towfish is cylindrical with length of 1.9 m, diameter of 0.20 m, and weight of approximately 70 kg in air (see Figure 5). Typical tow speeds were 3 to 5 knots. Maximum tow depths near 40 m were possible with 100 m of cable out and ship speed near 3.0 knots. During towing, the cable length in the water was continually adjusted to compensate for changes in ship's course and speed. A towfish altitude of 10 to 15 m above the seabed was considered optimal for image quality and mine detection, and as a safe height to avoid grounding to towfish. The Klein multi-beam echo processor, differential GPS navigation systems, and computer recording and display units were setup in the *Quest* lab.

**Figure 5** Deployment of the Klein 5500 towfish from the aft-deck of the *Quest*.

During all surveys except the first low-resolution survey in Herring Cove, the TrackPoint II acoustic positioning system was used. This system operated at frequencies near 30 kHz, measuring the position (range and bearing) of a self-contained transponder mounted on the Klein 5500 towfish. The master TrackPoint transducer head was mounted on the bottom of a 9.5 m long pole attached to the starboard side of the *Quest* aft-deck. This put the master transducer 6.75 m below the surface, and below the *Quest* keel and propellers. The system produced updates of the towfish position relative to the ship once every 2 seconds, which was recorded along with the ship's position, speed, and heading derived from differential GPS. This range and bearing information was used in post-processing routines to correct for towfish lay-back and cross-track position relative to the ship.

In the *low-resolution, wide-area* surveys conducted over all operating areas, the Klein 5500 was set to record data to 150 m slant range on both port and starboard sides. In this mode the

sonar sampled a nominally 300 m horizontal swath, leaving a near-nadir gap <10 m across. The surveys followed a series of parallel tracks aligned with the long dimension of the survey area, with spacing near 185 m (0.1 nautical miles) between tracks. After the deployment of the inert mines and in areas where the *Alliance* had collected seabed stereo photographs, a series of *high-resolution* surveys were performed. In this mode the sonar collected data to 75 m slant range with a cross-track resolution of 10 cm. Surveys lines were arranged in free-form manner over the mine targets, consisting of a number of passes to both port and starboard, at different angles of approach, and at different cross-track distances. Table 3.1 summarizes the Klein 5500 surveys.

**Table 3.1:** Summary of Klein 5500 survey operations. Times in ADT = UTC -3

| Date | Description | Start | End | Mode |
|---|---|---|---|---|
| July 4 | Herring Cove wide-area, northern part | 1128 | 1300 | Low, 150m |
| July 4 | Herring Cove wide-area, southern part | 1425 | 1617 | Low, 150m |
| July 5 | Herring Cove inert mines | 1435 | 1701 | High, 75m |
| July 6 | Herring Cove inert mines, stereo photo line | 1436 | 1644 | High, 75m |
| July 8 | St. Margaret's Bay wide-area, southern part | 0859 | 1140 | Low, 150m |
| July 8 | St. Margaret's Bay wide-area, northern part | 1310 | 1628 | Low, 150m |
| July 14 | Rose Bay wide area | 1443 | 1910 | Low, 150m |
| July 15 | St. Margaret's Bay inert mines | 1404 | 1552 | High, 75m |
| July 16 | St. Margaret's Bay inert mines | 1352 | 1545 | High, 75m |
| July 17 | St. Margaret's Bay inert mines, stereo photo | 1355 | 1610 | High, 75m |
| July 19 | St. Margaret's Bay stereo photo lines | 1052 | 1356 | High, 75m |
| July 19 | New Harbour Point wide-area | 1548 | 1710 | Low, 150 m |

Figures 6 and 7 show the sidescan image mosaics from the Herring Cove site. Processing of the Klein sidescan data was accomplished using the SIPS software package developed by DREA-MCM. These images are made by globally normalizing the echo-intensities to remove range and along-track variations, then plotting the geo-referenced pixels along each of the survey tracks. The software also allows smoothing of the navigation, towfish attitude, and towfish layback data. For the Herring Cove surveys without the TrackPoint towfish positioning a simple fixed correction was made for the towfish layback. Where adjacent swaths in the mosaic overlap a *pixel-averaging* process is used. All the sidescan mosaics shown herein were made using the basic 20 cm sonar resolution, then sub-sampled by a factor of 2 to make manageable file sizes for display.

The seabed in the Herring Cove site was dominated by flat sandy areas, with a few rocky shoals. The rocky areas have higher acoustic reflectivity and thus appear brighter (more white) on the images, with distinct dark lines due to shadowing in fissures and behind boulders. Shallower sandy and gravelly areas appear closer to shore in the NW corner of Fig. 5 and in the SW side of Fig. 7. An area of interesting gravel or vegetation striations or ripples is evident to the SSE of Lichfield Shoal. The rocky-gravelly shoal in the SE of Fig. 7 is un-named. A linear feature likely due to a buried cable can be seen heading SE-NW between Lichfield Shoal and the shore across the two figures. A detailed examination of the western half of Figure 6 reveals some *doubling* of small targets and a mis-alignment of the buried cable feature across overlapping swaths due to imperfect towfish lay-back and cross-track corrections.

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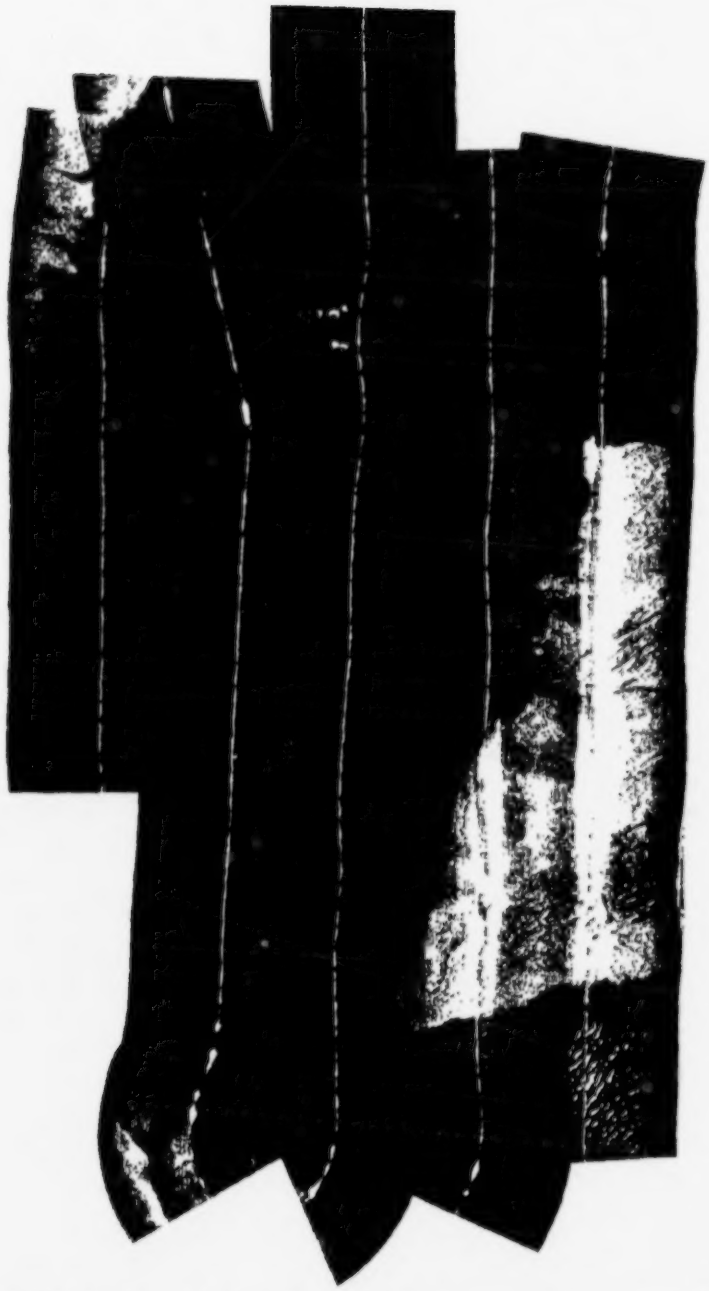

**Figure 6** Klein 5500 sidescan sonar mosaic of northern half of Herring Cove survey area. Bright area on the eastern side is Lichfield Shoal. Maximum north-south dimension is 1.85 km.

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**Figure 7** Klein 5500 sidescan sonar mosaic of southern half of Herring Cove survey area. Lichfield Shoal visible in NE corner. Maximum track length (along NW-SE line) is 1.80 km.

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**Figure 8** Klein 5500 sidescan sonar mosaic of St. Margaret's Bay survey area. Mosaic is rotated 90° counterclockwise (i.e. east is up), with dimensions 3.30 km east-west by 0.93 km north-south.

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Figure 8 shows the wide-area mosaic from St. Margaret's Bay. In this survey (and all that follow) the TrackPoint positioning system was used to measure the towfish position relative to the ship, producing significantly less target doubling and feature misalignment between swaths. The seabed sediments and the bathymetry at this site were more varied than at Herring Cove, dominated by muddy sands and muddy gravels. The dark area towards the SE was a deeper (roughly 52 m), muddy zone with very low acoustic reflectivity. The cross-track striations in this region were due to loss of bottom-tracking by the towfish altimeter. The wispy, high-reflectivity features at longer cross-track range in the western third and near the eastern edge of the image were due to ocean surface backscattering as the towfish was raised above 20 m deep shoals (with towfish >10 m above seabed). In these regions the good quality portion of the image is <50 m port/starboard of the centerline. In the center of the survey area there is a distinct north-south linear feature that spans several swaths, which was likely created by a vessel dragging its anchor.

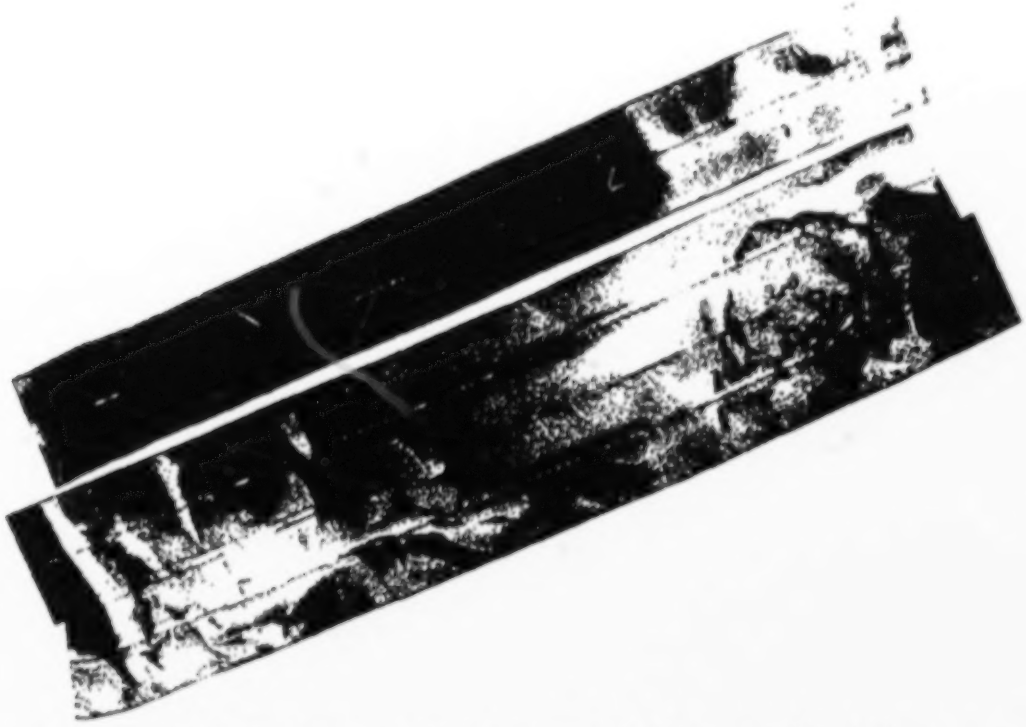

**Figure 9** Klein 5500 sidescan sonar mosaic of Rose Bay survey area. Maximum track length (along line WSW-ENE) is 1.70 km

Figure 9 shows the wide-area mosaic from Rose Bay. The seabed sediments here were dominantly sandy, with large areas of ripples interspersed with vegetation. The ripples trend fairly uniformly NE-SW, with a crest-to-crest length scale of about 1 m. A few rocky and gravelly areas can be seen on the southeastern side of the image. Some surface scattering effects are present, as this site was somewhat shallower (18 to 25 m) than other sites.

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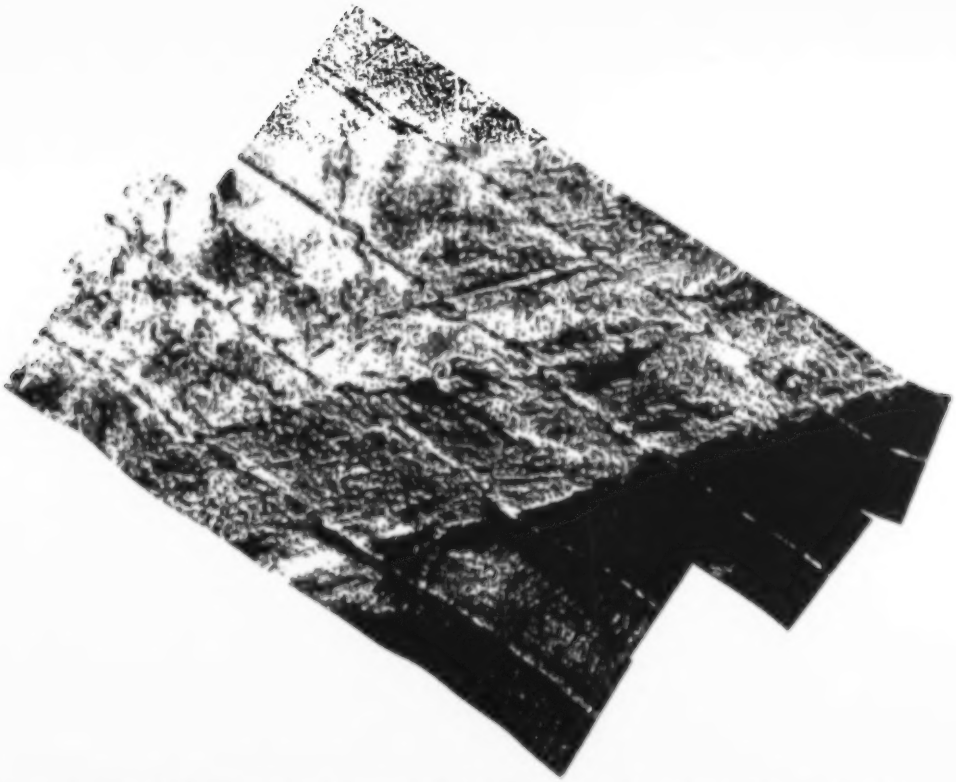

**Figure 10** Klein 5500 sidescan sonar mosaic of New Harbour Point survey area. Maximum track length (along line WNW-ESE) is 1.0 km.

Finally, Figure 10 shows the sidescan mosaic from the New Harbour Point area. This site is dominated by a hard bedrock outcropping approximately 18 to 20 m deep, with a flatter, deeper sand and vegetation area to the SSE. The bedrock is deeply fractured and gouged, with striations trending largely ENE-WSW, presumably created by glacial action. The dividing line between the rocky and sandy regions is very distinct.

The multiple inert mine-like objects were temporarily deployed and recovered from *Quest* twice during MAPLE, once on a sandy area near Herring Cove and once on muddy sandy seabed in St. Margaret's Bay. In both locations the water depth was 30 to 35 m. Inert mines were provided by DREA, SACLANTCEN, and borrowed from MARLANT MOG5. Mine shapes including advanced Manta and MP80 types, as well as conventional spheres and cylinders, were used. These inert mines were deployed in two or three mooring strings, with 4 to 6 mines on each string. Marker floats at one end of each string supported the retrieval lines. The length of rope between the individual mines in the string was about 60 m. The mine-strings were deployed from the *Quest* aft-deck, using a combination of winch and crane. It was suspected that the SACLANTCEN Manta was overturned in the Herring Cove deployment. In St. Margaret's Bay a string of 4 tethered mines (3 spheres and a cylinder) was deployed, with targets from 1 to 4 m above the seabed. In St. Margaret's Bay the deployment

condition of all the inert mines was inspected with the Phantom ROV. Tables 3.2 and 3.3 give the deployment locations and dimensions of the inert mines These positions were confirmed and fine-tuned through a combination of high-resolution sidescan image analysis and using the ROV position determined with DGPS and the TrackPoint system as it inspected each inert mine. Figure 11 shows a photographic collage of some of the inert mines.

**Table 3.2:** Positions and Dimensions of Inert Mines SE of Herring Cove. Two strings of inert mines (cylinders and mantas) were deployed from the *Quest*. The MOG5 cylinders were deployed in early June and remained on the seabed throughout the summer The corner group consisted of a small wooden lobster pot and a metal corner-reflector suspended from a 30 cm diameter float.

| Mine | Deployment Position | Dimensions |
|---|---|---|
| MOG5 cylinder #1 | N44° 33.466' W63° 32.836' | 1.83m x 0.61m dia. |
| MOG5 cylinder #2 | N44° 33.520' W63° 32.845' | 1.83m x 0.61m dia. |
| MOG5 cylinder #3 | N44° 33.575' W63° 32.860' | 1.83m x 0.61m dia. |
| MOG5 cylinder #4 | N44° 33.634' W63° 32.889' | 1.83m x 0.61m dia. |
| corner group | N44° 33.548' W63° 32.682' | |
| Six-foot cylinder | N44° 33.550' W63° 32.830' | 1.83m x 0.26m dia. |
| SACLANT cylinder | N44° 33.649' W63° 32.648' | 2.0m x 0.53m dia. |
| Stainless cyl. #1 | N44° 33.704' W63° 32.626' | 1.50m x 0.51m dia. |
| Stainless cyl. #2 | N44° 33.748' W63° 32.613' | 1.50m x 0.51m dia. |
| SACLANT Manta | N44° 33.584' W63° 32.543' | 1.0m base dia. x 0.39m high |
| Yellow Manta #1 | N44° 33.639' W63° 32.542' | 1.02m base dia. x 0.45m high |
| Yellow Manta #2 | N44° 33.675' W63° 32.519' | 1.02m base dia. x 0.45m high |
| Yellow Manta #3 | N44° 33.719' W63° 32.481' | 1.02m base dia. x 0.45m high |

**Table 3.3:** Positions, Dimensions of Inert Mines in St. Margaret's Bay. Three strings of inert mines (cylinders, mantas, and tethered) were deployed from the *Quest*. The corner group consisted of a small wooden lobster pot and a metal corner-reflector suspended from a 30 cm diameter float. SACLANT Rock was deployed on July 10th, but recovered on July 15th prior to any high-res sidescan surveys.

| Mine | Deployment Position | Dimensions |
|---|---|---|
| corner group | N44° 36.742' W64° 00.388' | |
| Stainless cyl. #1 | N44° 36.765' W64° 00.414' | 1.50m x 0.51m dia. |
| Stainless cyl. #2 | N44° 36.788' W64° 00.436' | 1.50m x 0.51m dia. |
| SACLANT cylinder | N44° 36.831' W64° 00.463' | 2.0m x 0.53m dia. |
| SACLANT Manta | N44° 36.688' W64° 00.569' | 1.0m base dia. x 0.39m high |
| Yellow Manta #1 | N44° 36.707' W64° 00.607' | 1.02m base dia. x 0.45m high |
| Yellow Manta #2 | N44° 36.719' W64° 00.626' | 1.02m base dia. x 0.45m high |
| Yellow Manta #3 | N44° 36.729' W64° 00.641' | 1.02m base dia. x 0.45m high |
| Yellow Manta #4 | N44° 36.752' W64° 00.668' | 1.02m base dia. x 0.45m high |
| Vertical cylinder | N44° 36.860' W64° 00.135' | 1.83m x 0.26m dia., 4m above |
| Syn. foam sphere #1 | N44° 36.909' W64° 00.137' | 0.45m dia., 4m above seabed |
| Syn. foam sphere #2 | N44° 36.937' W64° 00.134' | 0.45m dia., 3m above seabed |
| Steel sphere #1 | N44° 36.977' W64° 00.122' | 0.62m dia., 2m above seabed |
| Steel sphere #2 | N44° 37.012' W64° 00.117' | 0.62m dia., 1m above seabed |
| SACLANT Rock | N44° 36.654 W64° 00.402 | 1.0m x 0.6m x 0.4m approx |

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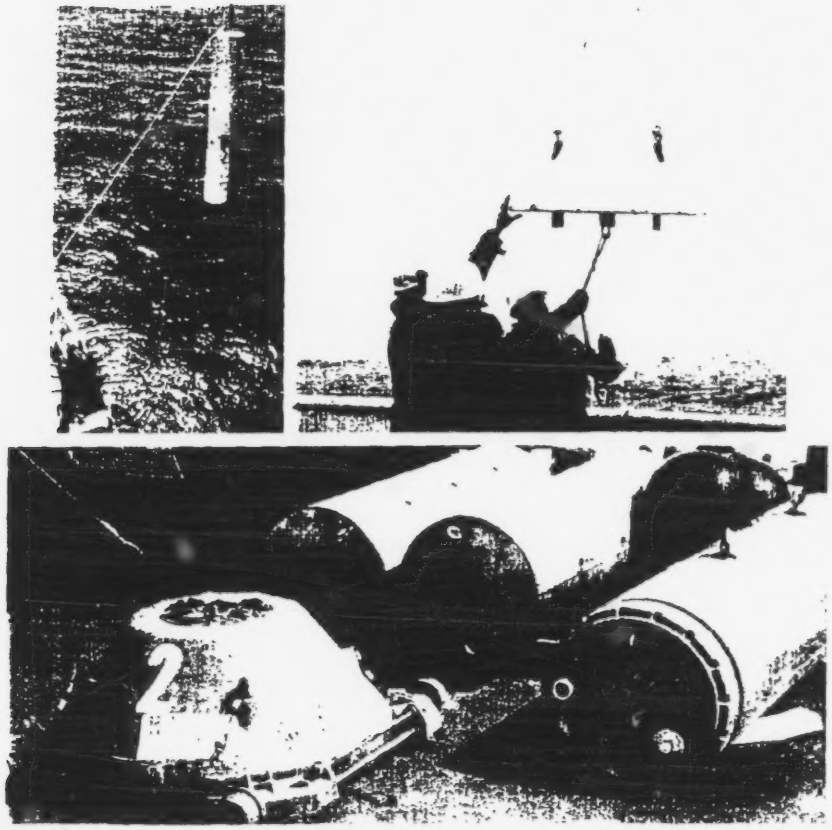

**Figure 11** Photographs of some of the inert mines during and prior to deployment. **Top left:** 6-foot cylinder; **Top Right:** DREA Manta; **Bottom:** Orange SACLANTCEN mines, Manta on left, MP80 cylinder on right. Two large stainless-steel cylinders from DREA can be seen in middle background.

The high-resolution Klein 5500 sidescan surveys were successful in obtaining good quality images of the mines targets and surrounding seabed in both Herring Cove and St. Margaret's Bay, as shown in Figure 12. These images will be useful as training and test data sets for the development of Computer-Aided Detection and Classification algorithms. The general character of each of the seabed mines is to have a bright reflection with a distinct, attached shadow that is often several times longer than the target echo. The length of the shadow is geometrically related to the towfish altitude, target range, and target height. The larger cylindrical mines are clearly easier to detect than the manta shapes, even at off-perpendicular incidence angles. Note an interesting *ringing* phenomena appearing after the target echo of two of the DREA stainless cylinders. These two cylinders were water-filled, and thus the ringing is likely due to multiple internal reflections. The signature of tethered (i.e. above seabed) mines is a long, narrow shadow disconnected from the target and/or anchor echo. The lobster pot and corner-cube reflector are also tethered objects, and the small hollow float

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used to suspend the corner-cube is clearly visible. Very little evidence of the mooring ropes was seen in any of the sidescan images.

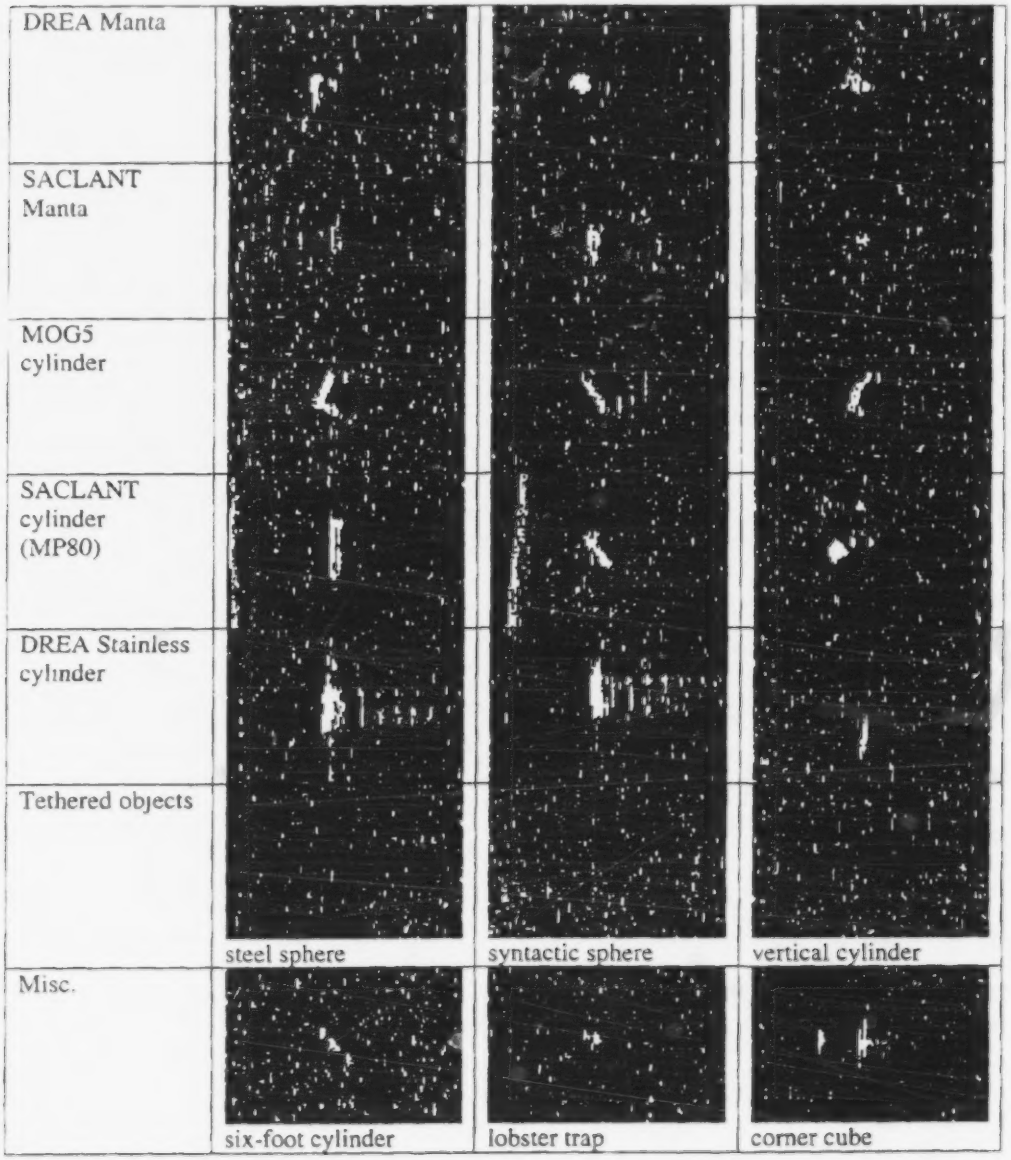


**Figure 12** Collection of high-resolution Klein 5500 sidescan sonar images of inert mines on the seabed in both Herring Cove and St. Margaret's Bay. Each image is 6 m x 9 m in size with 10 cm pixel resolution. Target images from port side are flipped to provide uniform left-to-right insonification.

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# 4. Overview of Sediment Penetrometer Tests

One scientific objective of MAPLE was to compare three different types of seabed sediment penetrometer: the Free-Fall Cone Penetrometer (FFCPT), STING, and XBP (eXpendable Bottom Profiler, provided by SACLANTCEN). These comparisons were conducted at several sites in St. Margaret's Bay, some of which were co-located with seabed sediment cores and stereo photographs taken by the *Alliance*. With appropriate ground-truth information the reliability of the probes can be assessed, making the probe data useful in future for in situ sediment typing in support of acoustic seabed classification tests. The FFCPT and STING probes were deployed from the *Quest*, while the *Alliance* deployed the XBP. Photographs of the three sediment probes are shown in Figure 13, with a summary of the sediment probe drop locations given in Table 4.1. Although not exactly co-located, some of the XBP probe drops are close enough to the FFCPT/STING drops to assume similar sediment conditions (assumption also supported by bathymetry and stereo photo data).

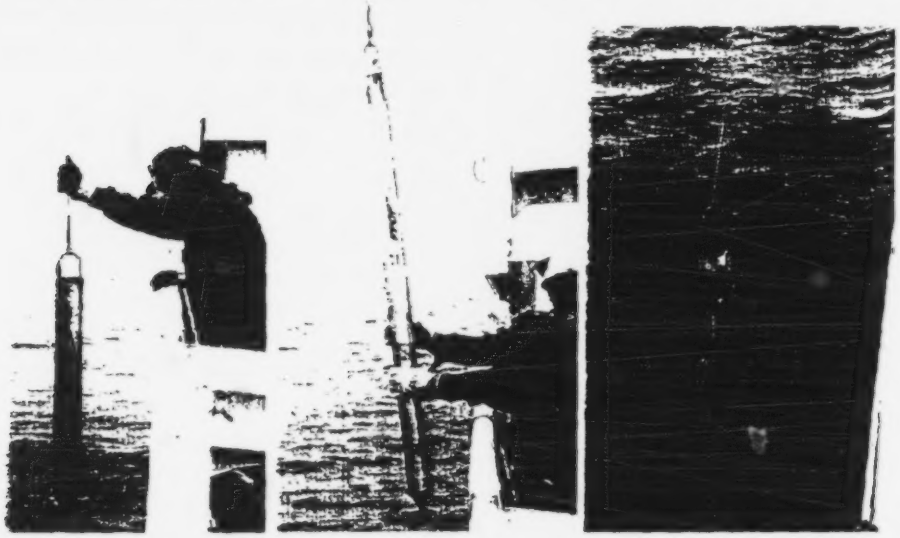

**Figure 13** Free-Fall Cone Penetrometer and STING deployments from the *Quest*. **Left**: older 4.5" FFCPT, **middle**: new 3.5" modular FFCPT; **right**: STING probe.

The FFCPT is a new self-contained device built by Brooke Ocean Technologies (Dartmouth, NS) for quantitatively measuring seabed sediment properties. Two versions of this device were tested during these trials: an older 4.5" (11.4 cm) diameter by 60 cm long prototype and a newly designed 3.5" (8.9 cm) diameter, 183 cm length modular probe. Each probe weighed roughly 50 kg in air. Additionally, two stabilizing fins sets mounted on the tail of the 3.5" probe were tested. The basic function of these probes was freely fall to the seabed and upon impact measure the deceleration and dynamic pore pressure time-series during penetration. These data permit calculation of vertical profiles of penetration resistance and pore-water overpressures, which together can be used to determine profiles of sediment type (e.g. type and grain size) and un-drained shear strength. Both instruments record data internally, with

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data sampling (approx. 500 Hz) triggered by a depth threshold. For each FFCPT deployment, the probe was allowed to free-fall from the surface to the seabed, typically in 40 to 50 m depth. Two drops with each prototype were taken at each site. The FFCPT prototypes were deployed from the aft-deck using a recovery line flaked out loosely on deck. A large drum winch was used to recover the probes. After each drop, the profile data was retrieved to a PC and the probe re-initialized.

The STING probe is an older sediment penetrometer developed and tested at DREP (now manufactured under license by JASCO Research, Victoria, BC). It's function and deployment are similar to the FFCPT, however the instrument only measures penetration deceleration and hydrostatic pressure (depth). The STING is composed of main sensor body, approximately 10 cm diameter by 40 cm long, with a 0.75" (1.9 cm) diameter by 1.2 m long stainless-steel shaft protruding below.

**Table 4.1:** Summary of FFCPT, STING, and XBP probe tests in St. Margaret's Bay.

| Date | Location | Time (ADT) | Probe |
|---|---|---|---|
| July 06 | N44° 36.62' W64° 00.60' | 1141 | XBP |
| | N44° 36.61' W64° 00.39' | 1311 | XBP |
| July 10 | N44° 36.75' W64° 01.54' | 0926 | XBP |
| | N44° 36.42' W64° 00.54' | 1519, 1540 | 4.5" FFCPT |
| | N44° 36.42' W64° 00.54' | 1550, 1604 | STING |
| | N44° 36.42' W64° 00.54' | 1625, 1652 | 3.5" FFCPT |
| | N44° 36.42' W64° 00.54' | 1827, 1844 | STING |
| July 11 | N44° 36.53' W63° 59.74' | 0949, 1001 | 4.5" FFCPT |
| | N44° 36.53' W63° 59.74' | 1014, 1025 | STING |
| | N44° 36.55' W63° 59.76' | 1323, 1415 | 3.5" FFCPT, float |
| July 12 | N44° 36.95' W63° 59.54' | 0913, 923 | XBP |
| | N44° 36.50' W64° 00.65' | 1504 | XBP |
| | N44° 35.45' W64° 00.96' | 1951 | 3.5" FFCPT, fins |
| July 13 | N44° 35.45' W64° 00.95' | 0820,0830 | 3.5" FFCPT, large fin |
| | N44° 35.45' W64° 00.96' | 0845, 0857 | 3.5" FFCPT, small fin |
| | N44° 35.45' W64° 00.97' | 0859, 0907 | STING |
| | N44° 35.44' W64° 00.96' | 0923, 0931 | 4.5" FFCPT |

Figure 14 shows an example data set from a drop of the 4.5" FFCPT in St. Margaret's Bay. The probe contains two pressure sensors, one on the top of the probe measuring hydrostatic pressure and the other on the tip, measuring dynamic pore pressure. The two pressure sensors are 0.6 m apart vertically. The instrument also supports two accelerometers, one with a ±2-g full scale and the other with a −10 g to +30 g range. Prior to impact the two pressure sensors displayed a linear increase in depth with slope (speed) of 5.7 m/s. During the descent the accelerometers showed near zero values, indicative that the probe had reached terminal fall speed where gravitational force was balanced by drag on the probe and tether. The accelerometers showed a strong impact deceleration (peak 30 g, possibly clipped) lasting approximately 15 ms, followed by a small, damped rebound. The 2-g accelerometer is completely overloaded. Note that in softer sediments the maximum deceleration would be less and the duration of impact would be long. A time-series of probe penetration depth below the seabed interface can be extracted from double-integration of the acceleration time-

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series, using the impact velocity (from pressure sensors prior to impact) and zero velocity at rest (i.e. after the impact) as constraints.

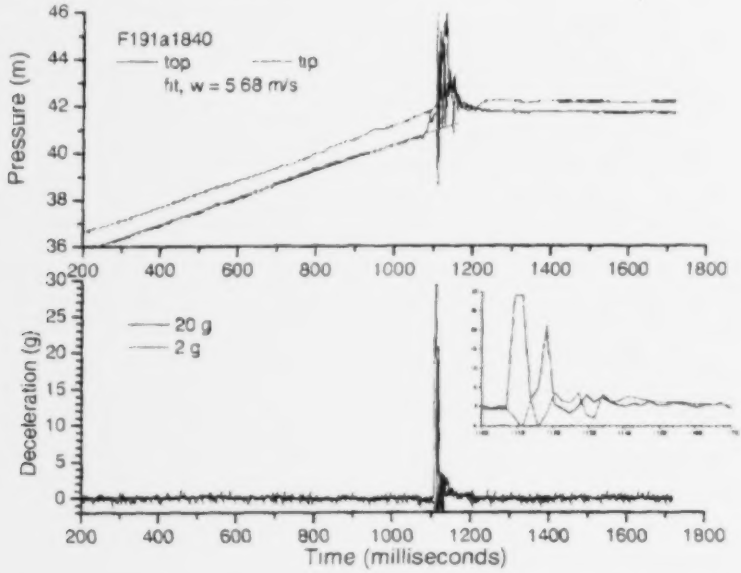


**Figure 14** Pressure and Acceleration time-series from the 4.5" FFCPT at 1540h July 10th in St. Margaret's Bay. Water depth = 42.5 m over gravelly sand. Impact occurred at 1107 milliseconds. Lower plot inset shows detail of impact deceleration.

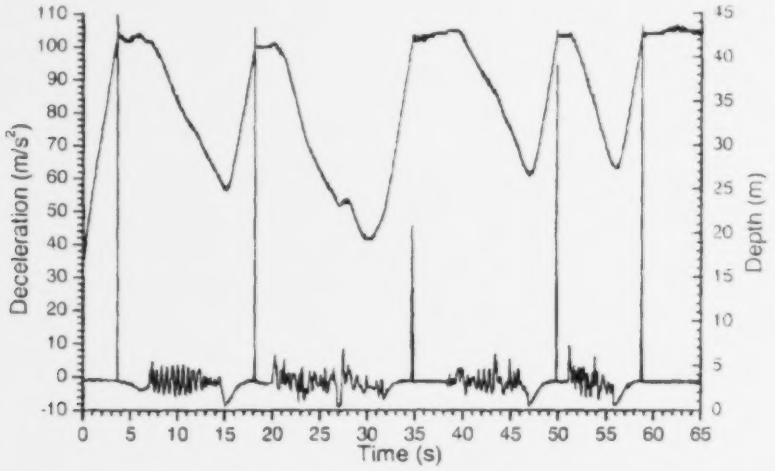


**Figure 15** Time-series of deceleration and depth from the STING probe deployed 0907h July 13th in St. Margaret's Bay. There are 5 separate impacts. Water depth = 43 m over muddy sand.

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Figure 15 shows an example of the STING data. This probe collects data at higher rate (2000 samples per second) for up to 64 s, initiated by a depth-trigger set at 30 m. During this deployment the probe impacted the seabed five times, being raised approximately 15 m and re-dropped after each impact. The average impact speed of 5.7 m/s is similar to the FFCPT. However, because of the smaller cross-section of the penetration foot the typical impact duration of 110 ms was longer and the typical peak deceleration of 100 $m/s^2$ (10.2 g) was smaller. As with the FFCPT, just prior to each impact the pressure sensor showed a linear increase in depth with time and the accelerometer reached near zero values, indicative that the probe had reached terminal fall speed. The STING analysis software performed a double-integration of the acceleration data, yielding probe penetration depths for these five drops of 30 to 40 cm.

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# 5. Overview of the Turbulence Experiment

This experiment was focused on measuring the time-variability of acoustic fluctuations created by water-borne turbulence. Specifically, it was expected that tidally generated turbulence was present in the near-seabed boundary layer. Acoustic fluctuations were to be sensed using a steerable, multi-frequency SACLANTCEN sonar (known as SLITTA) mounted on the top of a 10 m high tower deployed on the seabed by *Alliance* (see Figure 16). By insonifying the same region of seabed from a fixed location, spatial variations are removed. This experiment required that the instrumented tower remain fixed on the seabed over a period of roughly 6 hours. The *Alliance* chose to operate in a station-keeping mode during this deployment, with only 200 m long instrumentation cables connecting the tower and the ship. By observing the seabed echoes over many hours, and simultaneously measuring currents, water stratification, and turbulence, it was anticipated that correlations between acoustic and oceanographic fluctuations would emerge.

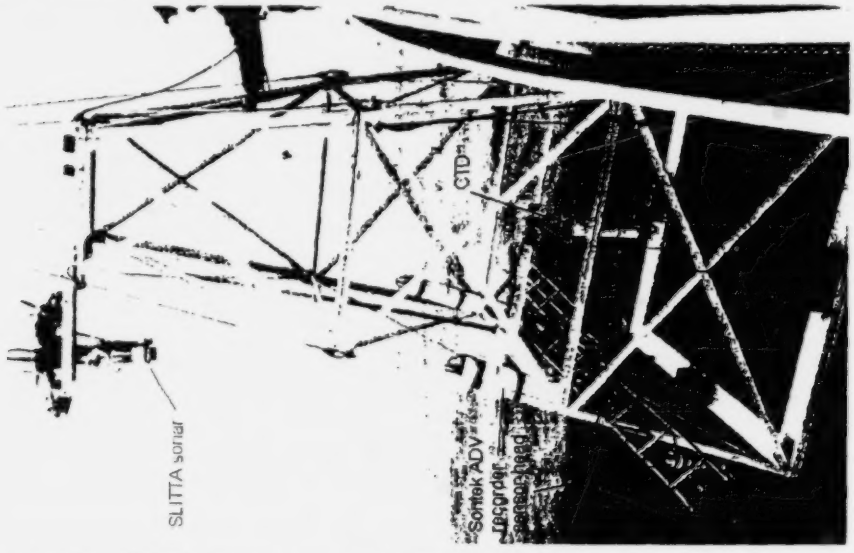


**Figure 16** SACLANTCEN acoustics tower with CTD and ADVs during deployment from *Alliance* in St. Margaret's Bay, July 12th. The thermistor chain was attached to near inboard leg of the tower.

This experiment was originally devised for the SE Herring Cove site, but due to equipment problems and operational considerations was moved to St. Margaret's Bay. The experiment was conducted jointly by the *Quest* and *Alliance* in St. Margaret's Bay on the morning of July 12th (0630 to 1300h). The *Alliance* deployed the tower at N44° 36.43', W063° 59.50', in water depth roughly 25 m. Two fast-time-response acoustic current meters, a thermistor chain, and a CTD were mounted on the tower to measure currents and water properties. During the night of July 11th some CTD profiles and ADCP measurements were made by the *Quest*, and CTD/ADCP data were collected all day on July 12th, including a period after the SACLANTCEN sonar had been recovered (see Fig. 20 for a typical CTD profile). Also, using the RHIB from the *Quest* multiple high-resolution turbulence profiles using the SCAMP

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instrument were conducted by the Dalhousie scientists near the tower. Figure 17 shows the wind speed and direction measured from the *Quest* before and during the turbulence experiments. During the turbulence experiments (0630h-1300h July 12th) the weather was foggy with light rain and light winds (<10 knots). Note that there was a fresh breeze (up to 22 knots) from the south for several hours during the early morning of July 12th. The low and high tides on the morning of July 12th were at 0735h and 1340h, respectively.

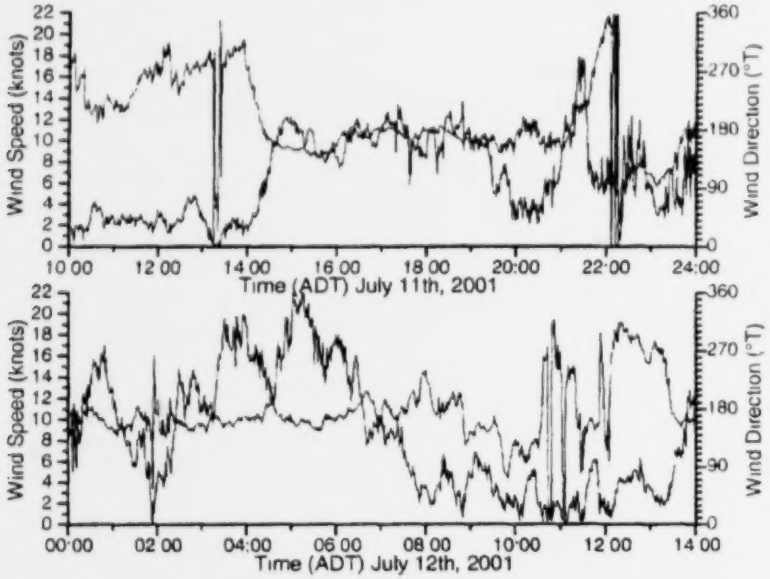


**Figure 17** True wind speed and direction from the *Quest* for the period 1000h July 11th until 1400h July 12th in St. Margaret's Bay

Dalhousie oceanography loaned two SonTek Acoustic Doppler Velocimeters (ADVs) for the turbulence experiment. These instruments use acoustic Doppler effect to measure 3 vector components of water velocity at a rate of 25 Hz. This relatively fast sampling rate allows (under some conditions) direct measurement of the turbulent kinetic energy dissipation rate, in addition to the tidal and wave-induced current components. The ADVs are relatively small, 10 cm diameter by 40 cm long, and completely self-contained. The small sensing volume lies approximately 20 cm in front of the sensor head. These instruments work at acoustic frequencies near 1.5 MHz, and thus would not cause acoustic interference with other sonars. The ADVs were mounted on the SACLANTCEN acoustics tower on open triangular spars projecting roughly 1 m out from each side of the tower and roughly 1 m above the seabed (see Fig. 16). One ADV recorded good quality data from 1600h July 11th until 1552h July 12th. The other ADV did not record, likely due to a mistake in configuring the instrument's operation schedule.

The 3-component current velocity from the tower-mounted ADV is shown in Figure 18. The raw 25 Hz data contain contributions from physical sources such as turbulence, surface swell, and tides. However these measurements are also convolved with instrumental limitations, the most serious of which is the inherent variance of Doppler estimation. A variety of filtering

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and averaging operations can be used to separate the different components. The 60-s-averaged data should remove swell-wave and turbulence contributions, leaving only the tides (and/or other background flows). The averaged vertical velocity is very close to zero, as it should be only 1 m above the seabed. During the strongest part of the flood tide (between 0900h and 1100h) the two 60-s-averaged horizontal components combine to yield a 3 to 5 cm/s current heading towards approximately 320°T. The 1-s-averaged data show contributions from surface gravity waves, with typical period near 8 s. Quantitatively, the 60-s-averaged X, Y, and Z-component variances are near 2.0, 3.0, and 0.5 cm/s, respectively, and show little variation in time. These variances are a combination of inherent Doppler variances, component averaging within the instrument, and turbulence. Further analysis will be necessary to determine the relative strength of turbulence and instrumental limitations.

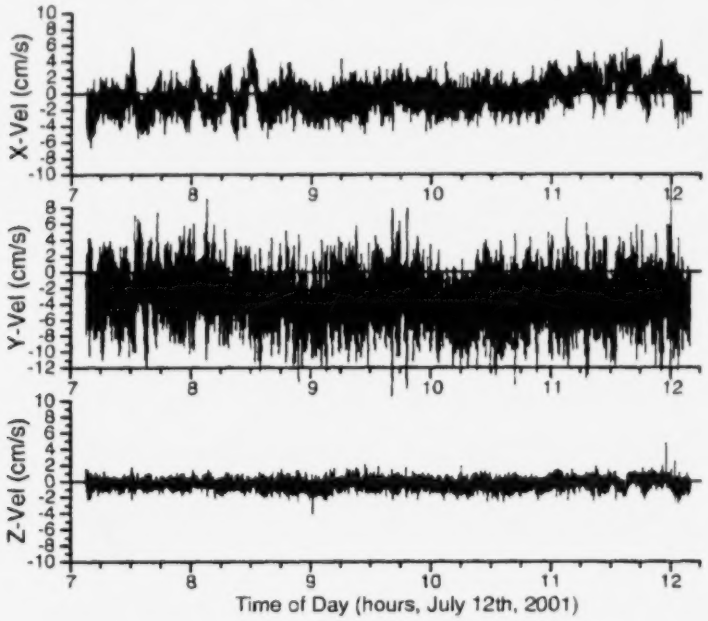


**Figure 18** Time series of 3 vector components of water velocity from the SonTek ADV mounted on the SACLANTCEN tower during the turbulence experiments, July 12th. Black lines are 1 s averages and red lines are 60 s averages. X and Y velocities are horizontal and Z velocity component is vertical.

During the turbulence experiment a hull-mounted 600kHz Acoustic Doppler Current Profiler (ADCP) was used for remotely measuring water velocity vs. depth profiles. This instrument resolves horizontal velocity vectors using the acoustic Doppler shift along four independent beams inclined 30° away from vertical, two beams in the alongships direction and two athwartships. The instrument uses a relatively short pulse for probing the water volume, and a longer bottom-tracking pulse for measuring the ship's velocity relative to the bottom. The water velocities for each ensemble are then referenced to the bottom-track velocity, removing ship motion artifacts. Due to the relatively small currents in this area, heavy averaging of the ping-to-ping velocities was necessary. For these turbulence experiments a depth-bin size of 2 m was used with ping-to-ping averaging of velocities over 54.8 s (50 ping) ensembles. ADCP

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data was collected from 1744h July 11th until 1832h July 12th while the *Quest* was both at anchor and under-way. Figure 19 shows three profiles taken on the morning of July 12th. In all cases the mean currents are small (< 10 cm/s), with distinct differences in the current direction between near-surface and near-bottom layers.

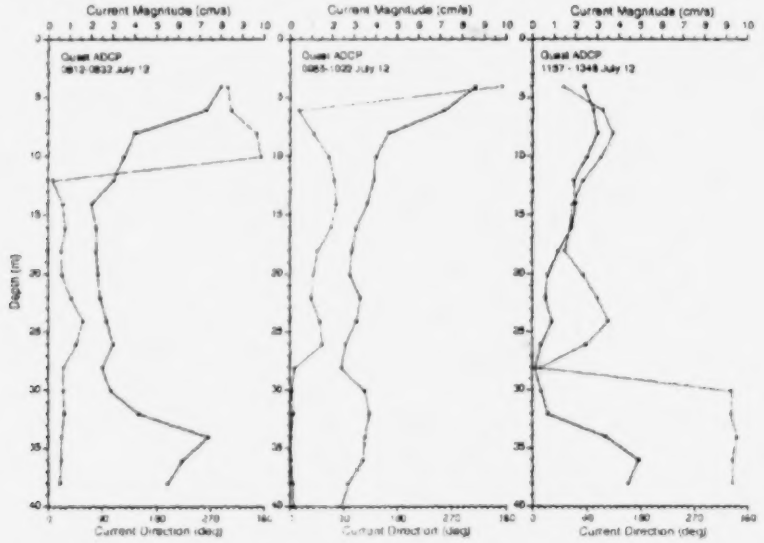


**Figure 19** ADCP profiles of mean current magnitude and direction from three different periods on the morning of July 12th. All three profiles were taken from the *Quest* in the vicinity of N44° 36.43' W63° 59.50' in water depth near 48 m.

The SCAMP is a self-contained, freely falling profiler which records water temperature with high spatial and temporal resolution. The temperature data are then used to determine the temperature wavenumber spectrum and thence to extract estimates of the turbulent thermal dissipation rate. The instrument is relatively small and light (10 cm diameter by 40 cm long, 10 kg), and thus is hand-deployable with only a light line attached to the probe for retrieval.. The instrument's terminal fall speed is approximately 50 cm/s. During the turbulence experiment on July 12th, SCAMP was deployed by Dalhousie Univ. personnel (B. Ruddick and D. Ciochetto) multiple times at a variety of locations near the tower.

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# 6. Summary of Other Data Collection

The SeaBird SBE-25 CTD is a self-contained instrument for highly accurate measurement of water temperature and conductivity vs. depth profiles. The instrument is calibrated to measure temperature and conductivity to accuracies approaching 0.001 °C and 0.001 S/m, respectively. The instrument is portable and completely self-contained, with a length approximately 1 m and weight of roughly 20 kg (in air). The data are recorded internally at a rate of 8 Hz, and then downloaded to a PC upon recovery. Table 6.1 summarizes the CTD data collected during MAPLE. The instrument was raised and lowered from the port-side hydrographic winch on the *Quest*. At the start of each deployment the instrument was lowered to just below the water surface and allowed to equilibrate for 60 s prior to commencing downward profiling. The winch speed was limited to approximately 20 cm/s. The CTD was lowered to approximately 3 m above the seabed, determined using a combination of water depth from the ship's echo-sounder and a counter on the sheave.

**Table 6.1** Summary of CTD stations. Data collected with SeaBird Electronics SBE-25 CTD instrument from the *Quest*. All times in Atlantic Daylight Time = UTC –3.

| File | Date | Time | Position | Max. Depth |
|---|---|---|---|---|
| q260_4001 | July 4 | 10.45 | N44° 32.51' W63° 32.09' | 36.38 m |
| q260_4002 | July 4 | 13 25 | N44° 32 48' W63° 32.05' | 36 74 m |
| q260_6000 | July 6 | 09·20 | N44° 34 01' W63° 32.45' | 30 09 m |
| q260_6001 | July 6 | 10·00 | N44° 32.54' W63° 32.07' | 37 50 m |
| q260_9000 | July 9 | 08 40 | N44° 36 54' W63° 59 49' | 45 90 m |
| q260_9001 | July 9 | 16.30 | N44° 36 52' W63° 59 51' | 45.52 m |
| q260_11000 | July 11 | 13.45 | N44° 36.56' W63° 59 78' | 45 58 m |
| q260_11001 | July 11 | 15·15 | N44° 36.46' W63° 59.53' | 47 56 m |
| q260_12000 | July 12 | 08 15 | N44° 36 43' W63° 59 50' | 46.01 m |
| q260_12001 | July 12 | 10:10 | N44° 36.43' W63° 59 43' | 47 03 m |
| q260_12002 | July 12 | 12·10 | N44° 36.45' W63° 59.58' | 45 92 m |
| q260_12003 | July 12 | 14·15 | N44° 36 43' W63° 59 58' | 45 84 m |
| q260_12004 | July 12 | 14 55 | N44° 36 39' W63° 58 88' | 45 44 m |
| q260_12005 | July 12 | 15.20 | N44° 37 05' W63° 59.62' | 41 23 m |
| q260_12006 | July 12 | 15.50 | N44° 36.42' W63° 59 59' | 44.94 m |
| q260_1800 | July 18 | 13:47 | N44° 36.41' W63° 59 52' | 44 97 m |

The raw CTD data (temperature, conductivity, and pressure) were post-processed according to the manufacturers recommendations, with low-pass filtering of the pressure and small corrections for thermal mass of the conductivity cell and vertical offset of the conductivity relative to the temperature sensor. Figure 20 shows a typical CTD profile from St. Margaret's Bay. The CTD data shows a very strong thermocline at 10 m depth, with temperature dropping from 10° to 4°C within a 3 m region and relatively well-mixed conditions above and below. The temperature near the bottom (2.7°C) was quite cold for July, indicating little mixing of the deeper waters of the Bay. This conclusion is reinforced by the modestly increasing salinity profile, increasing from 30.6 to 31.6 psu from surface to seabed. Salinity values <32 psu are indicative of enclosed coastal waters which are not mixed with more saline

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ocean waters. The sound speed profile shows a strong downward-refracting character in the thermocline region, with isovelocity conditions above and below.

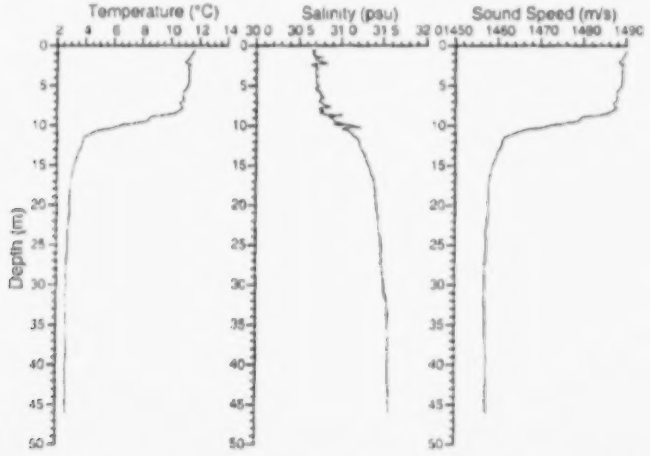


**Figure 20** Temperature, salinity, and sound speed profiles measured with the SBE25 CTD at 0815ADT July 12th in St. Margaret's Bay

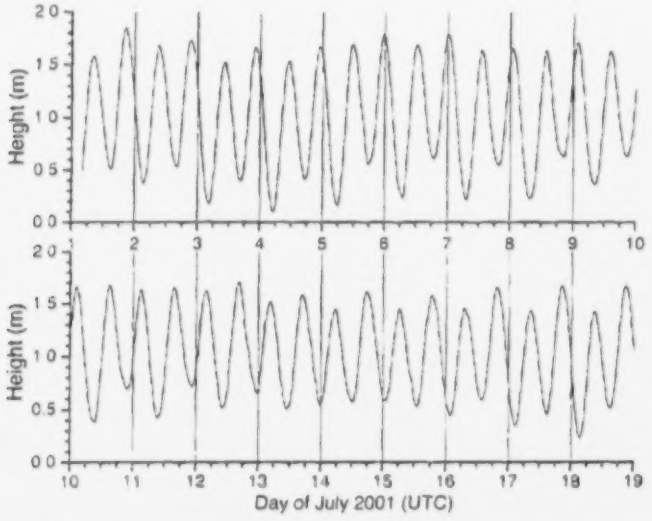


**Figure 21** Measured tidal elevation time-series from outer Halifax Harbour Data courtesy Dr. Charles Hannah, Bedford Institute of Oceanography

The tidal heights during MAPLE 2001 are an important reference, and are required to correct the swath bathymetric sonar data collected by the *Alliance*. These are routinely measured by the Bedford Institute of Oceanography through a series of tide gauges along the Nova Scotia coast. Figure 21 shows the measured tidal elevation during the experimental period from a gauge located in outer Halifax Harbour (near Herring Cove). Through both measurements

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and tidal modeling it has been found that the tidal elevation and timing are very similar for Halifax, St. Margaret's Bay, and Rose Bay, so these measurements can be applied to all the experimental sites.

On board the *Quest*, ship's position, speed, heading, engine status, and meteorological variables were collected continuously using the NADAS (Non-Acoustic Data Acquisition System). The normal sample interval for NADAS was 60 s, which was decreased to 10 s for ship's position and heading information during the high-resolution sidescan sonar surveys (this position information is in addition to independent DGPS data recorded by the sidescan sonar at 1 s intervals). The meteorological data included wind speed and direction (e.g. Fig. 17), air and sea surface temperature, barometric pressure, and relative humidity.

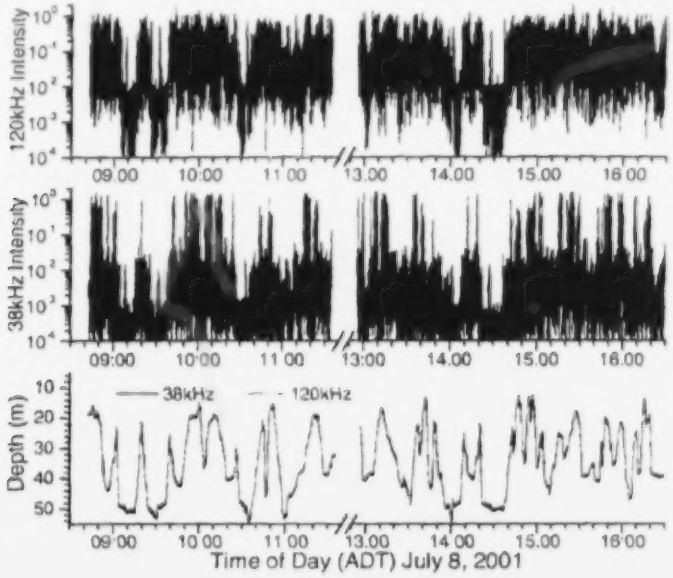


**Figure 22** Time-series of water depth and integrated bottom echo intensity from the 38 and 120 kHz echo-sounders on the *Quest*. Data from wide-area survey in St. Margaret's Bay, July 8th, 2001. Red line in upper two plots is smoothed (30 s averaged) intensity.

Two hull-mounted echo-sounders on the Quest were used on occasion during MAPLE. The Simrad three-frequency echo-sounder has been installed on the *Quest* since re-fit, but has only recently had the capability for digital recording. The system operates at 12, 38, and 120 kHz, however only the latter two were used. The depth measurement from the 120 kHz channel was recorded in the NADAS system. During the wide-area surveys of the 4 sites with the Klein 5500 sidescan, the water column and seabed echograms for both channels were recorded. These echograms contained water column to 50 m depth at 10 cm resolution, and bottom echo from 1 m above to 3 m below at 2 cm resolution, both at 1 s ping intervals. Figure 22 shows an example of the bottom echo intensity and water depth information from the wide-area survey of the St. Margaret's Bay site (i.e. at the same time as sidescan data shown in Fig. 8). In this analysis the bottom echo intensity was calculated from volume scatter strength data (i.e. with a 20log[range] time-varying gain) integrated over 1 pulse length

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(0.3 ms for 38kHz and 1.0 ms for 120kHz). The water depths from the two echo-sounders are essentially identical, with a consistent 45 cm offset. The seabed echo intensity data show large variations (3 orders of magnitude) which are partially correlated with water depth. Note the difference between strong echoes from the tops of rocky shoals versus the weak reflections from the soft muddy basins (>45 m depth). Also, the 38 kHz seabed echo data appear to give a greater variability than the 120 kHz, presumably because of greater sediment penetration in the 38 kHz data while the 120 kHz echo is dominated by roughness scattering. It is hoped that these spatial variations in scattering data will, when properly analyzed, prove useful for seabed sediment classification purposes.

The other echo-sounder system installed on the *Quest* is the X-Star sub-bottom profiler. This operates in the 2 to 15 kHz frequency band, with a variety of pulse types and lengths configurable by the operator. The relatively low-frequency and chirp processing allow imaging of sediment layers within the upper 5 to 10 m of the seabed. During MAPLE, the X-Star was operated during runs with the Klein 5500 sidescan along lines where the *Alliance* had performed seabed stereo photography. Generally, a 20 ms long, 2 to 15 kHz chirp pulse with a ping interval of 1 s was used. It is also considered possible to use this data for seabed sediment classification.

The Phantom Remotely Operated Vehicle is a small (1.2m x 0.9m x 0.7m) tethered vehicle which was used to acquire underwater video of the inert mines and to potentially assist in search and recovery of lost equipment. Figure 23 shows the Phantom returning to the *Quest* well-deck. Phantom has vertical and horizontal thrusters for maneuvering, video cameras, a manipulator arm, and sonar navigation equipment. It weighs approximately 75 kg in air. Power, control, and communications are carried through a 2 cm in diameter, 700 m long neutrally-buoyant umbilical cable. The *Quest* was anchored during Phantom deployments to avoid fouling the screws with the umbilical cable. The ROV was deployed and recovered from the well-deck of the *Quest* using the crane. Short (<1 hour) ROV deployments were conducted on the mornings of July 15th, 16th, and 17th to inspect the condition of inert mines on the seabed in St. Margaret's Bay. During these deployments, the TrackPoint acoustic positioning system was used to determine the range and bearing of the ROV from the ship.

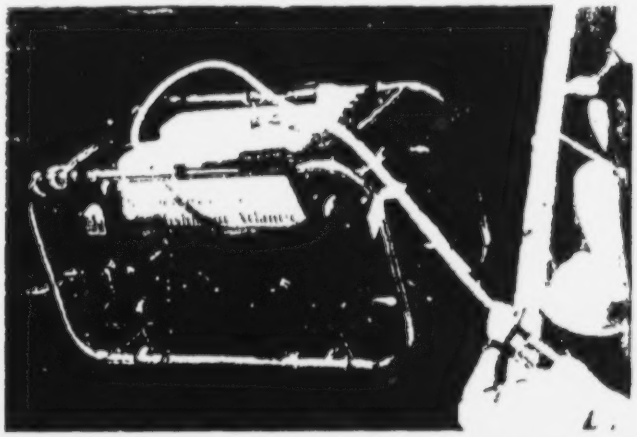

**Figure 23** Phantom Remotely Operated Vehicle during recovery on the *Quest*, July 16th in St Margaret's Bay.

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# 7. Summary Conclusions and Directions for Further Work

Overall the survey operations conducted during Q260 in collaboration with SACLANTCEN and the *Alliance* were successful in meeting the ambitious objectives of these joint sea-trials High-resolution sidescan sonar (*Quest*) and multi-beam bathymetric sonar (*Alliance*) surveys were conducted over 3 areas (Herring Cove, St Margaret's Bay, and Rose Bay) These survey areas were not small (between 1 and 3 square-kilometers in size), and thus constituted realistic mine-hunting environments spanning a variety of sediment types and water depths The *Quest* successfully deployed and recovered a variety of inert mines at the Herring Cove and St Margaret's Bay sites, and then collected multiple sidescan sonar images of these mines These sidescan mine signatures spanned a variety of ranges and incidence angles, over two different types of seabed sediments. At the same time *Alliance* focused its efforts on high-frequency acoustic seabed backscatter measurements, seabed stereo photography, and core samples Both vessels collected echo-sounder and sub-bottom profiler data that will be useful for evaluating various seabed sediment classification schemes. The four days of intensive testing of the FFCPT collected both good quality sediment profile data and constituted a thorough test of the new 3 5" prototype. Approximately 6 hours of coincident low-grazing angle sonar scattering and environmental data, including turbulence measurements by a team from Dalhousie Univ , were collected in St. Margaret's Bay Finally, three sites (St Margaret's Bay, Rose Bay, and New Harbour Point) were surveyed with sidescan sonar and two sites with multi-beam bathymetric sonars in fulfillment of a request from MARLANT N32.

In the immediate future, detailed analyses of MAPLE data along several themes should be pursued At the three main survey areas a detailed environmental picture can be pieced together from the acoustic and no-acoustic measurements, including sediment type, roughness, ripples, bathymetry, presence of vegetation, and presence of boulders.

Specific areas for research are.

- extraction and analysis of sidescan signatures of various mine targets with differing degrees of clutter and sediment type would ultimately permit reliable automatic discrimination between mine-like and non mine-like objects Quantitative mine signatures could include object height, size, and other mathematical descriptors of shape, along with similar quantifiers of the shadow. This catalog of mine signatures would be useful for training both human operators and computer-based classifiers (e g. neural networks)
- sidescan images of the same area before and after deployment of mine targets will be useful to assess *change-detection* algorithms for identifying recently lain objects.
- comparisons of stereo-photo roughness spectra (from *Alliance*) with quantitative measures of sidescan texture (*speckle*) will allow evaluation of techniques to remotely assess roughness and sediment type from the sidescan data.
- examination of techniques for fusion of the sidescan sonar, echo-sounder, and multi-beam bathymetric sonar data, with a view towards rapid environmental assessment in route survey operations

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- the EdgeTech X-Star and Simrad echo-sounder data should be processed using standard algorithms for seabed sediment classification. These data can then be compared with the standard RoxAnn data, seabed photographs, and core samples collected by the *Alliance*. These comparisons can be made over a variety of sediment types at the 3 different sites, and should yield insights into the usefulness of these algorithms using different echo-sounder frequencies and equipment. Also, the excellent ground-truth data should permit evaluation of new algorithms for sediment classification.
- detailed evaluations and comparisons of the seabed penetrometer (FFCPT, STING, XBP) profiles should made. Some interpretation of these results in light of the sediment classifications, seabed photographs, and other survey data will be necessary.
- the diverse environmental, turbulence, and acoustic data from the turbulence experiment need to be collated and put into context. The time-variations of scintillation in the acoustic returns from the seabed needs to be calculated.

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# Appendix 1: CFAV Quest Summary of Daily Activities

All times in Atlantic Daylight Time = UTC – 3. Locations: HC = Herring Cove, SMB = St. Margaret's Bay, RB = Rose Bay, NHP = New Harbour Point. DREA Personnel on-board for duration of sea-trials: M. Trevorrow (Chief Scientist), J. Fawcett, R. Kessel, A. Crawford, V. Myers, T. Miller, M. Rowsome, R. Arsenault, and R. MacDonald. Trinity Route Survey Office personnel on-board were Lt.(N) S. Moody and MS. C. Moncrief.

| Time | Activity |
|---|---|
| **Tuesday, July 3rd, 2001** | |
| 1035 | Quest departed Halifax dockyards NG, headed for Bedford Basin |
| 1135 | Anchored at N44° 41.37' W63° 38.67', testing anchor |
| 1200 | Began tests of FFCPT prototypes, multiple drops in 70 m depth |
| 1320 | Deployed GPTM pole, raised anchor, ran trials on pole up to 9 knots |
| 1500 | Further tests of FFCPT prototypes near Jonquiere Bank, drifting |
| 1600 | Test deployment of Klein sidescan, electrical problems |
| 1645 | Quest returned, tied-up at Halifax dockyards NG, unloaded FFCPT equipment |
| 1810 | Quest departed Halifax dockyards NG, heading for Shearwater |
| 1845 | Quest arrived, tied-up at Shearwater dock NA |
| | |
| **Wednesday, July 4th, 2001** | |
| 0830 | Quest departed Shearwater dock NA, deployed RHIB to carry chart to Alliance |
| 1000 | RHIB returned, recovered |
| 1045 | CTD at N44° 32.51' W63° 32.09' |
| 1115 | Deployed Klein SS, conducted low-res survey of HC site, northern part |
| 1300 | End of Klein SS surveys, northern part |
| 1325 | CTD at N44° 32.48' W63° 32.05' |
| 1422 | Deployed Klein SS, conducted low-res survey of HC, southern part |
| 1620 | End of Klein SS surveys, recovered towfish, headed back to Shearwater |
| 1730 | Quest arrived, tied-up at Shearwater dock NA |
| | |
| **Thursday, July 5th, 2001** | |
| 0820 | Quest departed Shearwater dock NA, headed for HC site |
| 0945 | Prepared inert mines for deployment, positioned ship |
| 1100 | Began deployment of 1st inert mine string, completed by 1140 |
| 1300 | Prepared inert manta mines for deployment |
| 1330 | Began deployment of 2nd inert mine string, completed by 1410 |
| 1430 | Deployed Klein SS, commenced multiple tows past inert mines |
| 1700 | Finished SS tows on inert mines, recovered towfish |
| 1830 | After 1 hour steam to Chebucto Head, tied-up at Shearwater dock NA |
| | |
| **Friday, July 6th, 2001** | |
| 0815 | Quest departed Shearwater dock NA, headed for HC site |
| 0920 | CTD at N44° 34.01' W63° 32.45' |
| 1000 | CTD at N44° 32.54' W63° 32.07' |

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| | |
|---|---|
| 1120 | XSTAR sounder run along W63° 32.95', S to N 1 mile, completed by 1200 |
| 1300 | Installed, tested Trackpoint system on GPTM pole, deployed pole |
| 1425 | Deployed Klein SS, commenced multiple tows past inert mines |
| 1625 | Commenced Klein SS tow along W63° 32.95', S to N, completed by 1645 |
| 1650 | Recovered Klein SS |
| 1720 | Recovered GPTM pole |
| 1830 | Arrived, tied-up at Halifax dockyards NG |
| | |
| **Saturday, July 7th, 2001** | |
| 0815 | Quest departed Halifax dockyards NG, headed for HC site |
| 0915 | Began recovery operations on inert manta mine string, completed by 1015 |
| 1045 | Began recovery of inert cylinder mine string, completed by 1130 |
| 1130 | Headed out to Chebucto Head, then around to SMB |
| 1725 | Quest anchored near Mill Cove in SMB |
| | |
| **Sunday, July 8th, 2001** | |
| 0700 | Raised anchor |
| 0820 | Deployed GPTM pole, then Klein SS towfish |
| 0845 | Commenced Klein SS low-res survey of SMB site, E-W lines |
| 1140 | Recovered SS towfish, break for lunch |
| 1300 | Deployed Klein SS, continued E-W survey lines |
| 1625 | Recovered SS towfish, run Quest for 1 hour |
| 1800 | Quest anchored near Mill Cove |
| | |
| **Monday, July 9th, 2001** | |
| 0700 | Raised anchor |
| 0745 | Commenced E-W line with 600kHz ADCP |
| 0840 | CTD at N44° 36.54' W63° 59.49' |
| 0900 | Commenced deployment of inert cylinder mine string |
| 1045 | Commenced deployment of inert manta mine string |
| 1300 | Launched RHIB, sent to shore in Mill Cove |
| 1445 | RHIB returned, then trip to Alliance, then recovered |
| 1515 | Commenced deployment of inert tethered mine string, finished by 1605 |
| 1630 | CTD at N44° 36.52' W63° 59.51' |
| 1800 | Quest anchored near Mill Cove |
| | |
| **Tuesday, July 10th, 2001** | |
| 0700 | Raised anchor |
| 0830 | Deployed pole, during deployment of Klein SS tore hole in cable, repairing |
| 0945 | Deployed RHIB to bring visitors from shore (Boutilier Point) |
| 1015 | RHIB returned from shore with J. Osler, H. Christian, and R. Kuwahara, then traveled to Alliance to bring 3 NATO visitors |
| 1310 | Deployed SACLANTCEN rock near N44° 36.65' W64° 00.40' |
| 1330 | Anchored Quest at N44° 36.42' W64° 00.54' |
| 1430 | Sent RHIB to Alliance with NATO visitors, returned 1630 |
| 1500 | Commenced sediment penetrometer drops (FFCPT, STING) |

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| | |
|---|---|
| 1700 | Break for supper |
| 1800 | Test deployment of repairs to Klein SS cable, 2 Sting drops, ended by 1900 |
| | |
| **Wednesday, July 11th, 2001** | |
| 0700 | Raised anchor |
| 0815 | Launched RHIB, carried 3 scientists (A. Crawford, R. Kessel, R. Kuwahara) over to Alliance, returned by 0830 |
| 0920 | Quest anchored at N44° 36.56' W63° 59.76' |
| 0930 | Prepared, deployed sediment penetrometers (FFCPT, STING) |
| 1045 | RHIB deployed to pickup Dalhousie scientists (B. Ruddick, D. Ciochetto) from shore (Boutilier Pt.), returned at 1145 |
| 1300 | Continued sediment penetrometer drops until 1400 |
| 1345 | CTD at N44° 36.56' W63° 59.78' |
| 1415 | Raised anchor, commenced E-W transects with ADCP and XSTAR |
| 1515 | CTD at N44° 36.46' W63° 59.53' |
| 1550 | Launched RHIB to pickup 3 scientists from Alliance, returned 1700 |
| 1820 | Quest anchored at N44° 32.29 W63° 58.83' |
| 1850 | RHIB deployed for tests of turbulence profiler |
| 1945 | RHIB returns, recovered |
| | |
| **Thursday, July 12th, 2001** | |
| 0715 | Launched RHIB, commenced turbulence profiles near Alliance |
| 0745 | Raised anchor, commenced E-W transects with ADCP and XSTAR |
| 0815 | CTD at N44° 36.43' W63° 59.50' |
| 0830 | Continued E-W transects |
| 1000 | RHIB returns, changed coxswain, returned to near Alliance |
| 1010 | CTD at N44° 36.43' W63° 59.43' |
| 1200 | RHIB returned |
| 1210 | CTD at N44° 36.45' W63° 59.58' |
| 1315 | RHIB departed to continue turbulence profiler work |
| 1320 | Deployed GPTM pole to test 100kHz sonar |
| 1415 | CTD and turbulence profile at N44° 36.43' W63° 59.58' |
| 1455 | CTD and turbulence profile at N44° 36.39' W63° 58.88' |
| 1520 | CTD and turbulence profile at N44° 37.05' W63° 59.62' |
| 1550 | CTD and turbulence profile at N44° 36.42' W63° 59.59' |
| 1600 | Recovered GPTM pole |
| 1620 | RHIB returned |
| 1740 | RHIB launched to take R. Kuwahara to shore, 1835 returned and recovered |
| 1930 | Quest anchored at N44° 35.45' W64° 00.94' |
| | |
| **Friday, July 13th, 2001** | |
| 0815 | Sediment penetrometer drops (FFCPT and STING), completed by 0930 |
| 1015 | SeaKing helicopter arrived for aerial photo operation |
| 1020 | Quest raised anchor, maneuvered close to Alliance for photos |
| 1130 | Helicopter departed, Quest now heading for Halifax |

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| | |
|---|---|
| 1700 | Quest arrived, tied-up at Halifax dockyards NG, visitors J. Osler and H. Christian departed |
| | |
| **Saturday, July 14th, 2001** | |
| 0915 | Quest departed Halifax dockyard NG, heading for RB, with visitor C. Smyth |
| 1400 | Arrived RB site, deployed GPTM pole and Klein SS towfish |
| 1445 | Commenced Klein SS surveys of RB site |
| 1640 | Recovered Klein SS towfish, break for supper |
| 1800 | Deployed Klein SS towfish, continued surveys, finished at 1835 |
| 1900 | Commenced single SS tow past wreck of HMCS Saguenay |
| 1920 | Recovered Klein SS towfish and GPTM pole, headed for SMB at 1930 |
| 2200 | Arrived in central SMB, drifted during night |
| | |
| **Sunday, July 15th, 2001** | |
| 0900 | Maneuvered, commenced recovery of the SACLANTCEN rock, 0920 finished |
| 1000 | Quest anchored at N44° 35.42' W64° 00.92' |
| 1055 | Phantom ROV ready, deployed for test dive |
| 1125 | Phantom ROV returned, recovered |
| 1300 | Deployed GPTM pole, then raised anchor |
| 1355 | Deployed Klein SS towfish, then commenced multiple SS tows on inert mines |
| 1600 | End SS tows, recovered SS towfish, recovered GPTM pole |
| 1700 | Quest anchored at N44° 36.42' W63° 58.88' |
| | |
| **Monday, July 16th, 2001** | |
| 0820 | Raised anchor, moved to position near inert manta mine string |
| 0920 | Quest anchored, deployed GPTM pole |
| 0950 | Launched RHIB, ferried A. Crawford and Capt. A. Grant over to Alliance |
| 1015 | RHIB returned, then departed for shore carrying visitor C. Smyth, and returning with visitors D. Jones and M. Kwiecinski |
| 1045 | RHIB returned, recovered |
| 1100 | Launched Phantom ROV for dive on inert manta mines |
| 1150 | Recovered ROV |
| 1300 | Raised anchor, moved to NE |
| 1320 | Launched RHIB to pickup parts from shore |
| 1345 | Deployed Klein SS towfish, made one tow past inert mines NE to SW |
| 1410 | Recovered SS towfish, received RHIB, then RHIB over to Alliance |
| 1445 | RHIB returned from Alliance with A. Crawford, recovered |
| 1450 | Re-deployed SS towfish, commenced multiple tows past inert mines |
| 1545 | Recovered SS towfish |
| 1550 | Tested GPTM pole in forward stowed position, then recovered |
| 1630 | Quest anchored in Mill Cove |
| | |
| **Tuesday, July 17th, 2001** | |
| 0815 | Launched RHIB with D. Jones for tests of BATS system |
| 0845 | Raised anchor, drifted near op area waiting for Alliance |
| 1020 | Maneuvered into position near inert cylinders, anchored by 1100 |

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| | |
|---|---|
| 1100 | Deployed GPTM pole |
| 1120 | Launched Phantom ROV for dive on inert cylinder mine string |
| 1155 | Recovered ROV |
| 1300 | Recovered RHIB, then raised anchor |
| 1340 | Deployed Klein SS towfish, then commenced high-res SS with XSTAR along E-W line at N44° 36.6'coincident with Alliance stereo photographs |
| 1435 | Continued multiple SS tows past inert mines |
| 1610 | Recovered SS towfish, then recovered GPTM pole |
| 1720 | Quest anchored near Shut-In Island N44° 33.60' W63° 57.20' |
| | |
| **Wednesday, July 18th, 2001** | |
| 0830 | Raised anchor, moving to inert mine area |
| 0950 | Completed recovery of inert manta mine string |
| 1100 | Completed recovery of inert cylinder mine string |
| 1200 | Completed recovery of inert tethered mine string |
| 1345 | CTD at N44° 36.41' W63° 59.52' |
| 1415 | Quest anchored near N44° 36.17' W64°00.90', tidying up inert mines on deck |
| | |
| **Thursday, July 19th, 2001** | |
| 0830 | Launched RHIB for test of BATS system |
| 0840 | Deployed GPTM pole |
| 1000 | RHIB returned, recovered |
| 1025 | Raised anchor, maneuvering |
| 1035 | Deployed Klein SS towfish, commenced 2 E-W lines with SS and XSTAR |
| 1215 | Recovered Klein SS towfish, break for lunch |
| 1320 | Deployed Klein SS towfish, commenced E-W line with SS and XSTAR |
| 1340 | Caught SS towfish in small fishing float, untangled with no damage |
| 1400 | Recovered Klein SS towfish, recovered GPTM pole |
| 1420 | Quest departed for NHP, arrived 1535 |
| 1535 | Deployed GPTM pole, then deployed Klein SS towfish |
| 1548 | Commenced 4 short survey lines at NHP, also XSTAR |
| 1709 | Recovered SS towfish, break for supper |
| 1820 | Recovered GPTM pole, disassembled pole |
| 1900+ | Quest steamed slowly back to Halifax |
| | |
| **Friday, July 20th, 2001** | |
| 0730 | Quest arrived, tied-up at Halifax dockyards NG (M. Rowsome bag-piper) |
| 1500 | Friendly soccer match between NATO and DREA teams, Shannon Park |

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(U) This memorandum summarizes experimental survey results acquired by the DREA mine counter-measures group during a joint sea-trial with the SACLANT Undersea Research Center, La Spezia, Italy. DREA utilized its ship *CFAV Quest* while the *NRV Alliance* supported the SACLANTCEN effort. The trials were conducted July 1 – 20, 2001 at four sites near Halifax, Nova Scotia. Each of the sites was approximately 1 by 2 km in area, with water depths of 30 to 50 m, overtop of mixed muddy, sandy, or rocky seabeds. At each site, high-resolution sidescan sonar surveys from the *Quest* were combined with multi-beam swath bathymetric sonar surveys from the *Alliance*. The *Quest* successfully deployed a variety of inert mine shapes at two sites, and then collected high-resolution sidescan sonar imagery of these mines at a variety of ranges and incidence angles. This data will be used for developing and testing computer-aided detection and classification algorithms. At the same time *Alliance* focused its efforts on high-frequency seabed backscatter measurements, seabed stereo photography, and core samples. Both vessels collected echo-sounder and sub-bottom profiler data useful for evaluating seabed sediment classification schemes. Multiple deployments of new and existing free-falling sediment penetrometers were conducted.

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sidescan sonar, sidescan mosaics, seabed mines, free-fall sediment probes, Halifax Harbour